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INSTITUTE FOR DEFENSE ANALYSES

**Analysis of Incidents of Crew Ejection from
Selected U.S. Tactical Fighter Aircraft**

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PREFACE

The Institute for Defense Analyses (IDA) prepared this document for the Office of the Director, Strategic and Tactical Systems, under a task titled "Costs and Benefits of the Installation of Certain Flight Safety Systems on the F-22 Aircraft." The objective of the task was to investigate and assess the life-cycle costs and benefits of potential flight-safety-related investments of the F-22. This document partially fulfills

that task by determining the frequency of and analyzing pilot ejection incidents, injuries, and fatalities for U.S. Air Force, Navy, and Marine Corps tactical fighter aircraft.

Kevin M. Eveker, Thomas P. Frazier, and George E. Koleszar of IDA were the technical reviewers for this document.

CONTENTS

Summary	S-1
Main Briefing.....	1
Appendix A. Supporting Slides	A-1
Appendix B. Air Force Review of IDA Study	B-1
Abbreviations	C-1

SUMMARY

BACKGROUND

Since 1996, the DoD and the U.S. Air Force have been interested in a lightweight derivative of the Russian K-36 class ejection seat for possible use in U.S. aircraft, including the F-22A fighter. Designated the K-36D-3.5A, the new seat uses state-of-the-art (SOA) technology and is believed to provide better injury protection (over a wide aircrew weight range) than the ejection seats currently used in U.S. Navy and Air Force aircraft, particularly at high speeds.

An improved version of the Air Force standard U.S.-produced Boeing Advanced Concept Ejection Seat II (ACES-II) is now planned for use on the F-22A. Another seat used on U.S. Naval fighters (including the F/A-18E/F) is the British Martin-Baker Navy Aircrew Common Ejection Seat (NACES) Mk-14. Modifications and upgrades to both the ACES-II and the NACES/Mk-14 to improve their performance are currently planned. Compatibility with a larger range of crew weights (to accommodate the lighter weights expected from female crews) is one of the improvements expected. Martin-Baker's newest seat, the Mk-16, incorporates a number of advanced features and SOA technology.

PURPOSE

This annotated briefing reports on the results of a study of the history of aircrew ejection incidents from several versions and seats on the F-15, F-16, F/A-18, and F-14 fighters with the purpose of answering the following questions:

- What has the U.S. experience been in terms of injuries and fatalities resulting from these incidents?
- How many of the unsuccessful incidents (those resulting in death or disability) projected for the F-22A could be prevented with SOA ejection seats?

FIGHTER AIRCREW EJECTION INCIDENTS

The following table summarizes the tactical fighter aircrew ejection incidents examined for all the aircraft and seats combined (F-15, F-16, F/A-18, and F-14). We examined a total of 522 ejection incidents, 55 for the F-15, 218 for the F-16, 68 for the F/A-18, and 181 for the F-14. We analyzed the unsuccessful ejections to estimate the number that could be prevented with SOA seat technology. For the ejection incidents examined with all four aircraft combined, we determined that about 16 "saves" would have been possible.

Summary of Results for All Aircraft Combined

Comparison Measure	Result
Ejection Incidents Examined (per Seat)	536
Resulting Ejection Rate per 100K Flying Hours	3.74
Number of Fatalities/Disabilities	44/3
Ejection Success Rate (% Without Fatalities/Disabilities)	91%
Unsuccessful Ejections Preventable With SOA Seat Technology	
Portion of Total Unsuccessful	~16 (34%)
Per Ejection	0.031
Per 100K Flying Hours	0.11

PREVENTABLE INCIDENTS ON THE F-22A

We used these results to project the total number of ejection incidents and unsuccessful ones expected with the F-22A and to estimate the number that could be avoided with SOA ejection seat technology. We used alternative approaches to derive an ejection rate of between 0.94 and 1.4 and potential "saves" between 1 and 2.

Because the validity of these predictions is rather uncertain, we attributed a conservative value of less than 3 saves due to SOA seat technology.

OBSERVATIONS

We found that the F-16, F-15, F/A-18, and F-14 fighters have an overall ejection success rate of about 90 percent, where

success is defined (in peacetime) as those incidents that do not result in death or permanent disability. The 10 percent of incidents that were unsuccessful (most of them fatalities) should obviously be reduced if possible. In wartime, the unsuccessful ejections would probably be expanded to include those producing major injuries (these would hamper rescue attempts and increase the likelihood of capture).

A few of the unsuccessful incidents could have been prevented and the severity of injuries sustained in other incidents could have been reduced with SOA ejection seat technology as currently or planned for use on the K-36, ACES-II, and NACES/Mk-16 seats.

Few of the ejection incidents we examined occurred at speeds above 500 knots, which appears to be the typical pattern for peacetime operations. In wartime, the average ejection speeds are likely to be higher than in peacetime. The effect of the F-22A's supercruise capability on average ejection speeds is not known.

CONCLUSION

New ejection seats with advanced features and SOA technologies are available that promise improved performance over currently fielded systems. However, improvements to ejection seats in fighter aircraft should be considered as one of a number of possible safety enhancements.

MAIN BRIEFING

1993 British Airshow



Successful K-36 ejection after midair

1989 Paris Airshow



Successful K-36 ejection at 300 feet
AGL, 100 knots, 80-degree pitch down

The Department of Defense (DoD) and the Air Force have had an interest in the Russian K-36 class ejection seat (manufactured by Zvezda) since the early 1990s. In 1993, U.S. military personnel began to evaluate the Russian K-36D ejection seat in a multistage DoD Foreign Comparative Testing (FCT) program. Phases I and II, held in Russia in 1993, completed wind tunnel, tower, and eleven high-speed tests. Phase III, held at Holloman AFB in 1995, included six low-speed and adverse-attitude tests.

The tests indicated that the K-36 ejection seat provides a higher overall degree of injury protection than the seats in currently fielded Air Force and Navy aircraft, particularly at high speeds or with lightweight (female) crews. A preliminary study completed in January 1995 concluded that the K-36D would fit in the F-22 fighter. Compared to the standard Air Force seat produced by Boeing, the Advanced Concept Ejection Seat II (ACES-II), the K-36D is much heavier (172 versus 236 pounds, respectively) and has a much larger headrest (constricting rearward visibility). The K-36D was consequently not selected for the F-22 at that time.

In August 1996, an advanced development program was initiated to develop a lightweight version of the K-36 to meet U.S. requirements. The new seat, called the K-36D-3.5A, retains the basic design features of the K-36D but is comparable in weight to the ACES-II. During the summer of 1998, six K-36D-3.5A seats were tested at the Holloman AFB sled track using Russian pyrotechnics, electronics, and flight equipment.

A risk-reduction effort began at that time to convert the pyrotechnic and electronic subsystems from Russian to U.S. manufacturers and to address the integration of U.S. life support equipment. Approximately \$21 million (not currently funded) is required to complete K-36D-3.5A Engineering and Manufacturing Development (EMD) to include subsystem and full system qualification for U.S. aircraft. Additional funding would be needed to integrate the seat on each designated applicable aircraft.

IBP Aerospace Group, Inc., and Zvezda have recently formed a joint venture to qualify and manufacture ejection seats in Hartford, Connecticut. Providing ejection seat technology options for the Joint Strike Fighter (JSF) has been the primary focus and schedule driver. However, Lockheed Martin is now interested in the suitability of the K-36D-3.5A for the F-22 due to Boeing's planned divestiture of ACES-II business and subsequent cost and schedule concerns. A preliminary integration study began in April 1999. The F-22 System Program Office has estimated K-35D-3.5A integration costs to be about \$18 million.

Given the current funding situation of the K-35D-3.5A, DoD was interested in documenting the historical ejection incidents from U.S. tactical fighter aircraft with the purpose of determining whether empirical data (alone) could justify continued EMD funding.

Background

- Russian K-36 ejection seat has been subjected to U.S. testing in several phases since 1993
- Current ejection seats on USAF and USN/USMC aircraft may not provide the same degree of crew protection as the K-36
- Modified Russian seat is now under study for the F-22A, JSF, and other programs
- K-36D-3.5A seat requires \$21M to qualify for U.S. programs and will need funding to integrate into each program (approximately \$18M for the F-22A)
- DoD is interested in documenting historical ejection incidents and results from U.S. fighter aircraft

There are a number of issues associated with current ejection seats on fielded U.S. fighter aircraft. The four main issues are ejection seat envelope expansion, ejection-related injury risk reduction, ejection seat accommodation range, and western manufacturing base stability. These issues, summarized here, are not all addressed in this briefing.

Expansion of the seat ejection envelope to provide increased altitude, speed, attitude, and sink rate for a safe ejection is a goal for future ejection seat capabilities. The Russian-made K-36 has demonstrated higher performance in some of these areas, particularly in the high-speed arena (with its windblast protection, telescoping stabilization booms, and other relevant features), than systems currently on U.S. fighter aircraft. The F-22A is projected to have a higher sustained speed capability than currently fielded fighters.

Reduction of injuries caused by aircrew ejection has been a longstanding objective for ejection seats. At high speeds, a perennial problem has been flail-related injuries to unrestrained limbs. The Russian K-36 system includes leg restraints and elevators as well as arm restraints. The Mk-16 system, an ejection seat made by the British firm Martin-Baker Aircraft Company, has leg restraints and two types of arm/leg restraint options, passive and active.

The occupant weight design range for the standard Air Force ACES-II ejection seat is 140 to 211 pounds, which represents the 5th through 95th percentile of the military male size range. The recent introduction of women into combat aircrew positions changes the weight and center of gravity that

may be ejected. An estimated 55 percent of military females are outside the ACES-II weight design range; current screening criteria allow female aircrew members at weights as low as 103 pounds. The risk of injury is higher for these smaller, lightweight crews with currently fielded ejection seats. Increasing the capability to accommodate a larger aircrew population, ranging in weight from 103 to 245 pounds, is thus a major ejection seat issue.

As documented in a 1997 Department of Commerce report,¹ the Western ejection seat manufacturing base has been severely eroded by the reduction of new fighter procurement and past policy decisions. The U.S. now has only one currently active producer, Boeing, and its status is highly uncertain given its apparent desire to divest itself from the business. The British firm Martin-Baker has the largest share of the Western market today, and is poised to further consolidate its position. This could result in a potential monopoly situation for the firm. The Zvezda Design Bureau in Russia is the sole supplier of ejection seats for Russian fighters and is (along with Martin-Baker) aggressively targeting the U.S. market. The K-36D-3.5A is now licensed to IBP, which intends to make the seat in the United States.

¹ *National Security Assessment of the Emergency Aircraft Ejection Seat Sector*, U.S. Department of Commerce, November 1997.

Current Fighter Ejection Seat Issues

- Ejection envelope expansion
 - Increase attitude, altitude, speed, and sink rate for safe ejection
 - Russian-made K-36 has demonstrated higher performance than systems currently on U.S. fighter aircraft
 - F-22 will have high sustained speed capability
- Ejection-related injury risk reduction
 - Reduce flail injuries at high ejection speeds
 - Russian-made K-36 system includes limb restraints, telescoping stabilization booms, and wind-blast protection
- Ejection seat accommodation range
 - Increase range of crew weight and height allowable
- Western manufacturing base stability
 - Boeing—status highly uncertain
 - Martin-Baker—U.K. manufacturer
 - K-36 licensed to new U.S.-located ejection seat developer/producer* to be qualified for U.S aircraft

* IBP is a British-owned firm.

This chart illustrates current seats of the three primary manufacturers of fighter ejection seats and lists their applications in presently fielded tactical fighter aircraft.

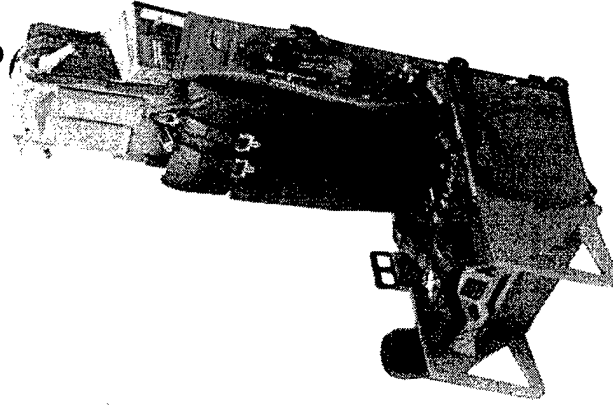
Since the late 1970s, Boeing (formerly McDonnell Douglas) has produced the ACES-II ejection seat for U.S. Air Force fighters. The F-15, F-16, A-10, and F-117 all have basically the same standard ejection seats. Some of these seats were retrofitted on existing aircraft, while others were installed on new aircraft. The B-1 and B-2 bombers use a slightly modified version of the ACES-II seat. The F-22 is planned to be equipped with a further modified ACES-II seat.

Martin-Baker Aircraft Company is the world's largest manufacturer of ejection seats. Its seats are currently used on U.S. Navy and Marine Corps fighters. The F-14A/B models are

equipped with the GRU-7 (Mk-7) seat, whose technology dates from the 1960s. Most of the F/A-18A/B/C/D fleet is equipped with the SJU-5 (Mk-10) seat, which represents 1970s-level technology. The F-14D and late-model F/A-18C/Ds are equipped with the Mk-14 Navy Aircrew Common Ejection Seat (NACES). The NACES was first installed on these aircraft in 1989 and is now the standard seat for all Navy production aircraft, including the F/A-18E/F. Zvezda is the Russian manufacturer of the K-36 class of ejection seats. The K-36D is installed on all Russian fighter aircraft, including the MiG-29 Fulcrum and Su-27 Flanker. The origin of the K-36 ejection seat was in the late 1960s. The version being considered for use in the F-22 is the K-36D-3.5A.

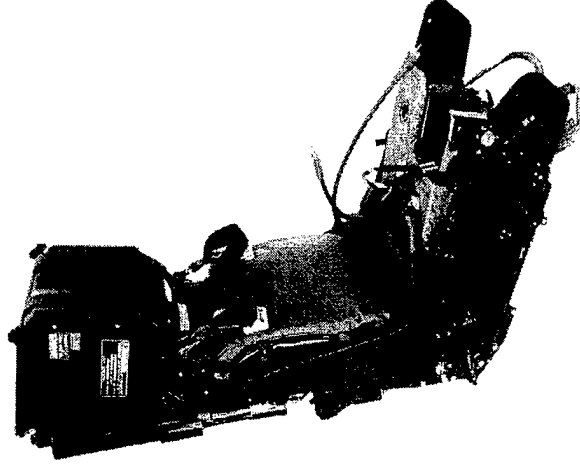
Primary Fighter Ejection Seat Manufacturers

Boeing (formerly
McDonnell Douglas)



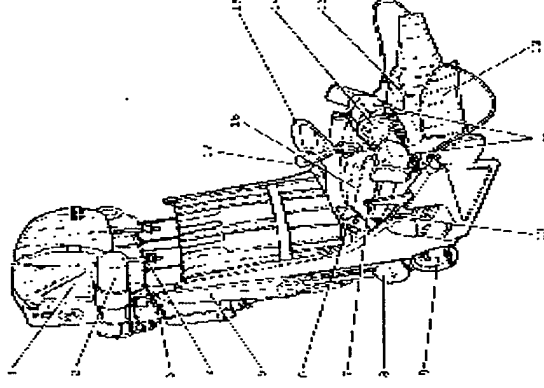
F-15: ACES-II
F-16: ACES-II
A-10: ACES-II
F-117: ACES-II
[~ 1979 New/Retrofit]

Martin-Baker (British)



F-14A/B: GRU-7 [1969]
F/A-18A-D: SJU-5 [1979]
F/A-18C-F: NACES [1989]
F-14D: NACES [1989]

Zvezda (Russian)



MiG-25/29/31: K-36
Su-27/35: K-36
[~ Late 1960s (originally)]
Current version being tested in
U.S. is K-36D-3.5A

The modified ACES-II ejection seat now planned for the F-22A includes a number of features that are not included in the standard version. This slide summarizes the main improvements incorporated on the modified ACES-II seat.

The most significant feature of the modified seat is probably the incorporation of a faster-acting drogue parachute system. This feature promises to improve seat stability and reduce the risk of injuries resulting from acceleration.

Arm and leg restraints are also being added to the seat. These will encapsulate the limbs to reduce the risk of potential flail injuries. It is interesting to note that limb restraints were on the original design for the ACES- II seat, but were removed due to pilot resistance at that time. Only a special version of the ACES-II on the B-1 has limb restraints now. Another improvement is a 50-cubic-inch oxygen system for emergency descent from altitudes in excess of 50,000 feet. The oxygen capacity provides breathing gas for a longer duration while

positive-pressure breathing offers protection from the effects of high-altitude exposure.

The ACES-II was originally designed, tested, and qualified for all-male aircrew members ranging in weight from 140 to 211 pounds. The recent introduction of women into combat aircrew positions changes the weight and center of gravity that may be seen. Current screening criteria allow female aircrew members as low as 103 pounds.

A cooperative program between the Air Force Aeronautical Systems Center and the Japanese government is now addressing ways to accommodate a larger range of aircrew weights (103 to 245 pounds) on the ACES-II seat. The goal of the program is to develop an upgrade kit of ACES-II seat modifications that will reduce the risk of high-speed ejection injuries to smaller, lightweight occupants, as well as increase protection to the overall population.

Improved ACES-II Features Planned for the F-22A

- **Fast-acting drogue chute system to improve seat stability to reduce possible injuries resulting from acceleration**
- **Arm and leg restraints that encapsulate arms and legs to reduce risk of potential flail injuries**
- **Integral 50-cubic-inch oxygen system to improve emergency descent capability from altitudes in excess of 50,000 ft**
- **Enhanced seat accommodation (possible) to provide lightweight crew compatibility (~103 lb)**

The Martin-Baker NACES (on F-14Ds, F/A-18E/Fs, and some F/A-18C/Ds) and Mk-16 (on the Rafale, Eurofighter, Boeing X-32, JPATS, and others) are the only currently fielded ejection seats that have microprocessor control of event sequencing tailored to the ejection conditions. Seat-mounted sensors are used to independently assess ejection conditions. These two seats offer very fast reaction times, approximately 0.31 seconds for parachute deployment at typical takeoff/landing speeds. Martin-Baker is currently exploring further improvements to these seats.

For the Mk-16, the NACES functional and performance features were repackaged into a new modular core design with a range of optional features. Leg restraints are standard on the seat and a garment-based arm restraint is optional. The Mk-16 system includes a unique steerable parachute with low opening loads and descent rates.

Improved aircrew accommodation range is already incorporated in the basic Mk-16 and is planned as part of the NACES P3I. The Mk-16 has a compound vertical adjustment feature, which moves the seat up and forward for enhanced crew reach.

Numerous advanced features are under consideration for the NACES P3I and Mk-16 P3I ejection seats. One is thrust vector control for trajectory shaping in adverse attitude conditions near the ground or water. Another potential improvement is the use of inflation devices for crew restraint, seat stabilization or airflow control at high ejection speeds. Yet another area being explored is the use of aircraft data through a data bus interface for further optimization of ejection sequencing or automatic ejection capability.

Improved Martin-Baker Ejection Seats:

NACES P3I and Mk-16/P3I

- Improved microprocessor control of event sequencing tailored to ejection conditions (acceleration, speed, barometric altitude) and aircrew weight
 - Seat-mounted sensors for independent assessment
 - Faster deployment time
- Modular design with full range of optional features
 - Standard leg restraints and optional garment-based arm restraints
 - Unique steerable parachute with low opening loads and descent rates
- Improved aircrew accommodation range
 - Compound vertical adjustment capability
- Advanced features under consideration
 - Thrust vector control/trajectory shaping
 - Inflatable devices
 - Aircraft data bus interface

The issues associated with the Russian K-36 ejection seats fall into five distinct categories, safety, competition, ergonomics, availability/acquisition, and operations/support. This slide lists some of the pros and cons associated with each of these areas.

In terms of aircrew safety, the K-36 series ejection seats offer a larger envelope, primarily in the high-speed (dynamic pressure) region but also potentially for adverse attitudes as well. The K-36 is designed to provide safe ejection capability at speeds over 700 knots equivalent airspeed (KEAS). Multiple injury-prevention features are incorporated on the K-36, and it already accommodates a wide aircrew weight range. On the other hand, modifications to the ACES-II seat for the F-22A are planned to increase its capability for injury mitigation. All of the seats, if qualified for higher speeds would require comparable improvements in other auxiliary life support equipment (such as the Air Force LPU-9 life vest and SRU-21 survival vest). Another area of concern is that detailed injury statistics (similar to those contained in this briefing) for the K-36 are unknown.

As documented in the 1997 Department of Commerce report, the ejection seat industrial base has decreased

significantly over the past decade. A benefit of having the K-36 available for use on U.S. fighters would be more competition and, subsequently, more innovation. However, a major disadvantage is that the market barely supports the companies now, and Boeing appears eager to divest itself from the business.

In terms of availability and acquisition, the K-36D is on a number of Russian tactical fighter aircraft now. An "Americanized" version of the lightweight derivative K-36D-2.5A would require approximately \$21 million for a qualification program and separate integration costs for each program. The K-36 seat is not yet a form, fit, function (F3) replacement for the ACES-II. Integration on the F-22 has been estimated at \$18 million. A U.S. manufacturing facility is being established (under a Russian license) for the K-36D-3.5A ejection seat, but the associated production costs for it are highly uncertain.

Finally, there has been a long experience base for operating and supporting the current ACES-II and NACES ejection seats within the U.S. Air Force and Navy, respectively. The operations and support cost and associated maintenance requirements for the K-36 series ejection seat are unknown.

Russian K-36D-3.5A Seat Issues

Issue	Pros	Cons
Safety	• Higher speed envelope (> 700 KEAS) potential (dynamic pressure) • Multiple injury- prevention features • Accommodates wide crew weight range • Possibly improved overall adverse attitude envelope potential	• ACES-II NACES intended to achieve higher speed envelope (now <450 KEAS) and include limb restraints • If qualified at higher speeds, all three seats would require comparable improvements in other life support systems • Detailed injury statistics and reliability data unknown
Competition	• More competition; more innovation	• Market does not support companies now; Boeing trying to sell ACES-II business
Ergonomics		• Crew mobility/visibility and comfort unknown
Availability/ Acquisition	• On a number of Russian tactical fighter aircraft now • Tested under Foreign Comparative Technology program and further testing by AFRL	• Russian license to American company; not "Americanized" (standardized to U.S. aircraft) • Qualification program estimated cost \$21M; integration on F-22 estimated cost \$18M (not F³ compatible) • Production cost not known relative to improved ACES-II on F-22A (ACES-II estimated at 150K each) • No U.S. experience in development and manufacture
Operations/ Support		• O&S cost and maintenance requirements unknown

This slide outlines the main questions addressed in this briefing. The first question addressed is:

- What has been the experience in terms of injuries and fatalities from U.S. tactical fighter aircrew ejection incidents?

The aircraft examined are the F-15A/B/C/D/E (ACES-II seat), F-16A/B/C/D (ACES-II seat), F/A-18A/B/C/D (all seats), and F-14A/B/D (all seats). Based on the data, a second question is:

- What are the projected ejection incidents (and injury spectra) from the F-22A (based on historical experience) and how many unsuccessful ones are potentially preventable with state-of-the-art ejection seat technology?

A third question is:

- What may be different in the future (for the F-22) in terms of physical size of pilots, peacetime training, and combat operations?

There are a number of pertinent areas of interest not addressed in this briefing. These include an examination of the ejection seat industrial base and associated issues and a detailed cost-effectiveness analysis of the ejection seat alternatives for individual aircraft programs. Detailed follow-up of ejection-related injuries (such as with hospital records) was not performed.

Questions Addressed

- What has been the experience of U.S. Tactical Fighter aircrew ejection incidents, injuries, and fatalities?
 - F-15A/B/C/D/E, F-16A/B/C/D [ACES-II seat only]
 - F/A-18A/B/C/D, F-14A/B/D [all seats]
- How many F-22A aircrew-ejection fatalities could be potentially prevented with state-of-the-art ejection seat technology?
- What might be different (for the F-22) in the future?
 - Physical size of pilots
 - Peacetime operations and training
 - Combat operations

This chart provides a top-level overview of the results from the tactical fighter aircrew ejection incidents we examined to answer the first question. Results are shown for individual aircraft and all the aircraft combined. A wide range of metrics is displayed in the table. The rates displayed are per the standard 100 thousand flying hours.

As a reference, we include the overall lifetime number of Class-A mishaps suffered through 1998 and the associated lifetime mishap rate per 100 thousand flying hours. Class-A mishaps are those with reportable damage over \$1 million and the most serious injuries (death or total disability). The Class-A mishap range for the individual aircraft span from a low of 2.2 for the F-15 to a high of 5.42 for the F-14, with a combined average number of 3.74.

The 522 ejection incidents examined was composed of 55 for the F-15 and 218 for the F-16 from 1979 through 1998 and 68 for the F/A-18 and 181 for the F-14 from 1980 through 1998. The corresponding ejection rates for the individual aircraft range from 1.47 for the F-15 (consisting of mostly single aircrew members) to about 9.52 for the F-14 (consisting of mostly two aircrew members) for an aircraft rate of 4.76.

The number of ejection-related fatalities and disabilities span from six for the F-15 to nineteen for the F-14. The ejection success rates by aircraft range from about 89 percent for the F-15 to approximately 93 percent for the F-16. While not listed, the success rates by seat were 89 percent for the GRU-7 and SJU-5, 92 percent for the ACES-II, and 100 percent for the NACES.

We analyzed the unsuccessful ejections (those resulting in death or permanent disability) to estimate the number potentially preventable with state-of-the-art (SOA) seat technology. This analysis considered the features and estimated performance of the Russian K-36 and Martin-Baker Mk-16 seats relative to that of the particular seat involved in the unsuccessful episode. Based on this analysis, we determined a total of about seven potential "saves" for the F-15 (three) and F-16 (four) combined and about nine for the F/A-18 (two) and F-14 (seven) combined. We divided these values by the number of ejections and flying hours to obtain the fraction of unsuccessful ejections potentially preventable with SOA technology per ejection and per 100 thousand flying hours (FH), respectively.

To answer the second question, we used the data in the table to project the number of ejection incidents expected from the F-22A and the number of unsuccessful ones that could be potentially preventable with SOA technology. The Air Combat Command (ACC) projects the F-22A will have a lifetime Class-A mishap rate of between 1.4 and 2.1. If its ejection rate per Class-A mishap rate equates to that experienced by the F-15 (1.47/2.2), then the projected ejection rate range of the F-22 would be 0.94 to 1.4. We multiplied this range by the unsuccessful F-15 ejections potentially preventable with SOA technology (0.055) and the cumulative number of F-22A flying hours divided by 100k (roughly 25). That yielded 1.3 to 1.9 as the number of unsuccessful ejections from the F-22 that would be potentially preventable with SOA technology.

Summary of Aircrew Ejection Incidents

Comparison Measure	Combined	Actual				Estimate
		F-15	F-16	F/A-18	F-14	F-22
Overall Class-A Aircraft Mishaps	536	82	244	107	103	35-53
Overall Class-A Aircraft Mishap Rate per 100k FH	3.74	2.2	4.34	3.47	5.42	1.4-2.1
Ejection Incidents Examined (per seat)	522	55	218	68	181	24-35
Resulting Ejection Rate per 100k FH	3.64	1.47	3.88	2.21	9.52	94-1.4
Number of Fatalities/Disabilities	44/3	5/1	16/0	5/1	18/1	2-4
Overall Ejection Success Rate (Without Fatalities/Disabilities)	91%	89%	93%	91%	90%	>90%
Unsuccessful Ejections Potentially Preventable With State-of-Art Seat Technology (Percent of Total Unsuccessful)	~16 (34%)	~3 (50%)	~4 (25%)	~2 (33%)	~7 (37%)	1-2
Unsuccessful Ejections Potentially Preventable With State-of-Art Seat Technology per Ejection	0.031	0.055	0.018	0.029	0.039	0.05
Unsuccessful Ejections Potentially Preventable With State-of-Art Seat Technology per 100k FH	0.11	0.080	0.071	0.065	0.368	0.06

Note: Time periods examined (largely peacetime): CY80-CY98 for F/A-18 and F-14; CY79-CY98 for F-15 (ACES-II only) and F-16.

Given the planned flying-hour schedule (~2.5M FH total) and missions, F-22A pilot ejection fatalities potentially preventable with state-of-the-art seat technology is less than three (for peacetime training).

Alternatively, we obtained a 1.9 value by multiplying the number of unsuccessful F-15 and F-16 ejections potentially preventable with SOA technology per 100 thousand FH (0.76) by the cumulative number of F-22A flying hours divided by

100 thousand (roughly 25). Given the uncertainty of the prediction, we assumed a value less than 3, as shown on the chart.

This slide outlines the scheme used for classifying the aircrew ejection injuries. Air Force Instruction (AFI) 91-204, *Safety Investigation and Reports*, describes four basic levels of injuries: fatal, disability, lost workday, and not reportable. The Navy uses a similar taxonomy, except it separates the not reportable incidents into first aid and none. A fatal injury are those that result in death either in the mishap or at any later time due to the injuries arising from the mishap. Fatal injuries from aircrew ejection are considered a failure.

Disabilities resulting from the mishap injuries are divided into two categories; permanent partial and permanent total. Disability injuries resulting from aircrew ejection are also considered a failure.

Lost workday injuries are those that result in one or more lost workdays. Lost workday injuries are divided into major and minor categories. A major injury involves admission to hospital, restriction to quarters, or a combination of both, for 5 or more days. It also includes any of the following, regardless of hospital status:

- Unconsciousness for more than 5 minutes due to head trauma

- Fracture of any bone, except simple fracture of the nose or phalanges
- Traumatic dislocation of major joints or internal derangement of a knee
- Moderate to severe lacerations resulting in severe hemorrhage or requiring extensive surgical repair
- Injury to any internal organ
- Any third-degree burns or any first- or second-degree burns (including sunburn) over 5 percent of the body surface.

A minor lost workday injury is an injury less than major that results in one or more lost workdays. Ejection episodes that result in major or minor loss workday injuries are considered a success for peacetime. In wartime, major lost workday injury levels may be detrimental to aircrew recovery efforts.

No reportable injuries are those that are minimal (including first aid treatment or observation) and do not result in a lost workday. This level of injury is obviously considered a success, and is the goal for all ejection episodes.

Aircrew Ejection Injury Classifications

- **Fatal injury: Failure**
 - Injuries resulting in death, either in the mishap or at any later time, due to injuries arising from the mishap injury
- **Disability: Failure**
 - Disabilities resulting from mishap injuries are divided into two categories, permanent total and permanent partial
- **Lost workday injury: Success (for peacetime)**
 - An injury not resulting in death or disability but with one or more lost workdays
 - Major: Admission to hospital and/or restriction to quarters for 5 or more days or certain specific injuries
 - Minor: Injury less than major resulting in one or more lost workdays
- **No reportable injury: Success**
 - No injuries occur or injuries are minimal and do not result in a lost workday

Source: AFI 91-204.

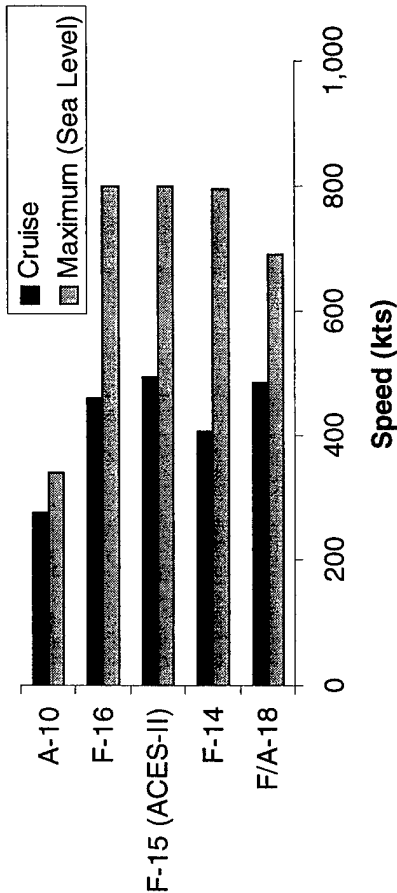
Aircraft speed at the time of the ejection has a major influence on the likelihood and severity of aircrew injury. This slide presents a summary of the aircraft speed performance capability (illustrated by the cruise and maximum sea level speeds) and the average and median speed at the time of ejection (across all the largely peacetime incidents reviewed) for a number of tactical fighter aircraft.

The top figure on the chart clearly shows the A-10 has the lowest cruise and maximum (sea level) speed capability of the aircraft considered. The bottom figure shows that all the

aircraft considered have roughly comparable median and average crew ejection speeds. (Ironically, the median and average ejection speeds for the A-10 are even slightly higher than those for other aircraft, which have much greater speed performance capabilities.) This demonstrates the fact that, when possible, the pilot attempts to obtain the safest (e.g., low-speed) flight conditions prior to ejecting. Again, this data represents the ejection speeds observed during peacetime; combat ejection incidents may result in higher average and median values.

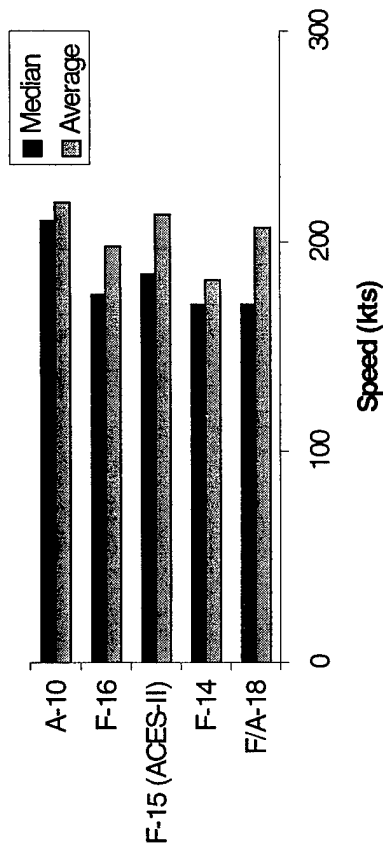
Crew Ejection and Aircraft Speed Comparison

Cruise/Maximum (Sea Level) Speed



A-10 has lowest cruise and maximum (sea level) speeds

Ejection Speed



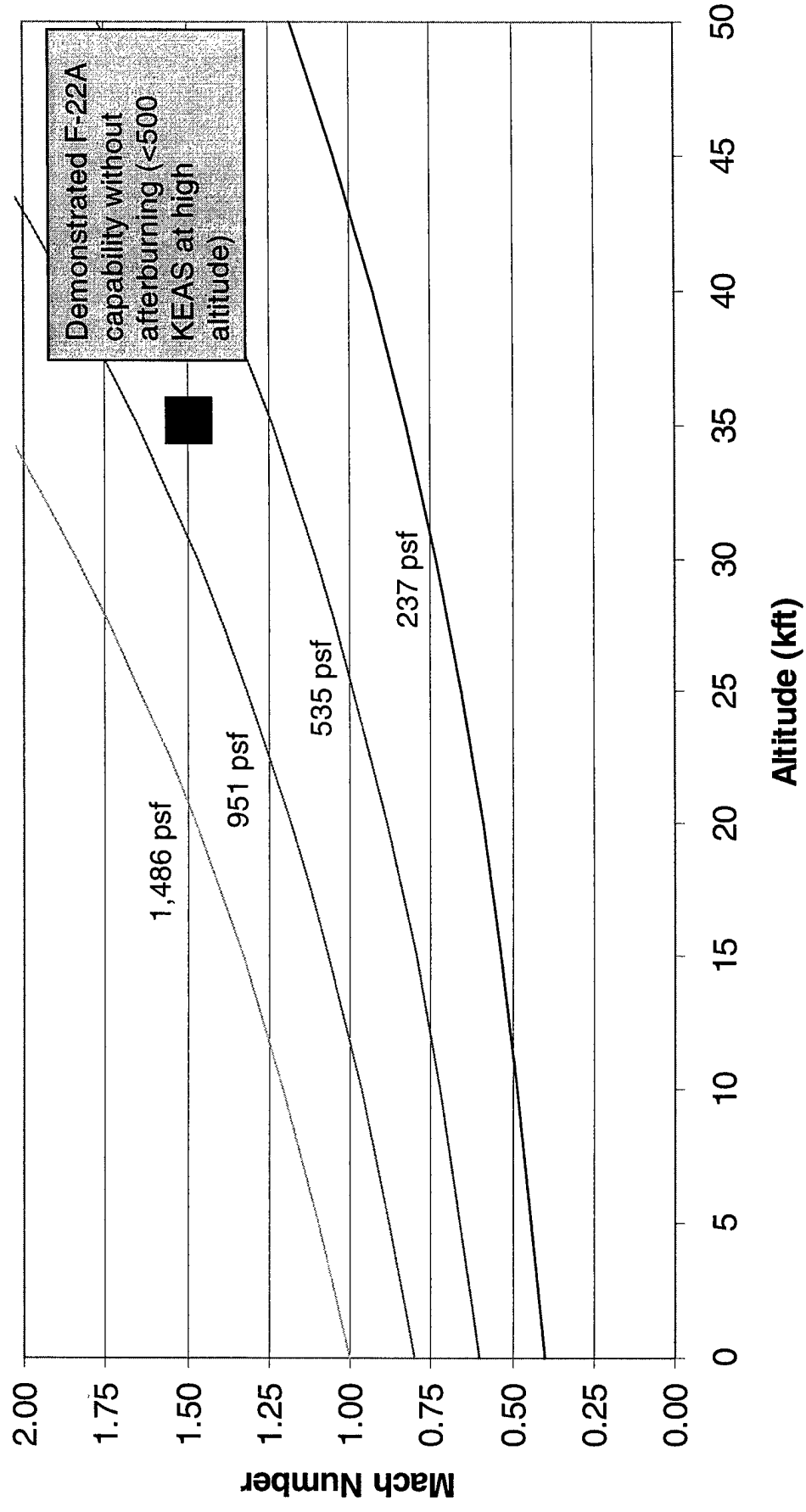
All aircraft have roughly comparable median and average crew ejection speeds (mostly peacetime); when possible, pilot attempts to generate safe ejection condition

One of the unique traits of the F-22A is its ability for sustained flight at supersonic speeds without the use of the engine afterburners. This is accomplished at high altitude, where the air density is reduced. The "supercruise" capability has been used to suggest an increased ejection injury risk level for the aircraft. If we disregard the previous chart (which indicated that the aircraft performance has had little bearing on the peacetime ejection speeds observed), any change in injury risk would depend on how often the aircraft flies at supercruise speeds and what the specific altitudes are (because ejection injury potential increases with the dynamic pressure or equivalent air speed, not the true airspeed).

This chart displays the relative dynamic pressures in pounds per square foot (psf) across a range of Mach numbers and altitudes. They are based on the Standard Day Atmosphere. The top line is the dynamic pressure associated with a speed of 660 KEAS. The bottom line is the dynamic pressure associated with a speed of 264 KEAS.

The demonstrated F-22A supercruise capability in initial flight tests places it between the middle two dynamic pressure lines, which represent 396 KEAS and 528 KEAS. Continued flight-testing is planned throughout the EMD phase to verify the performance capabilities of the F-22A, including the supercruise speed and altitude limits.

Relative Dynamic Pressures



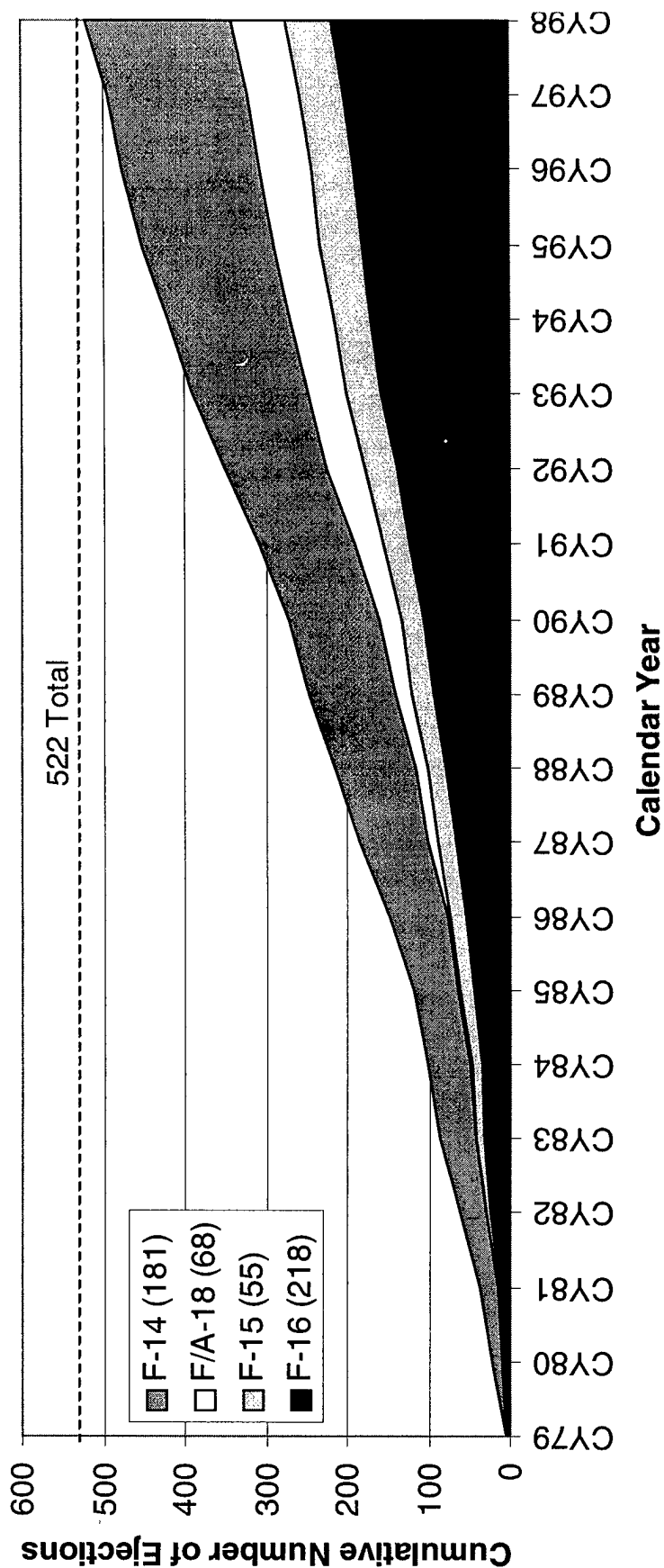
This chart illustrates the crew ejection history over the time period considered for the aircraft examined. Of the 522 ejection episodes reviewed, 181 were from the F-14, 68 were from the F/A-18, 55 were from the F-15, and 218 were from the F-16.

The ejection seat types involved were the ACES-II for the F-15 and F-16; GRU-7 (primarily) and NACES for the F-14, and SJU-5 (primarily) and NACES for the F/A-18. Where

applicable, ejection episodes from two-seat model aircraft were considered individually.

Overall, there has been a relatively steady rate of ejection episodes (per year) from these aircraft. The number of ejection episodes has averaged about 27 per year. For the aircraft combined, the number of ejection incidents (per seat) has been about 3.6 per 100,000 flying hours.

Crew Ejection History by Aircraft

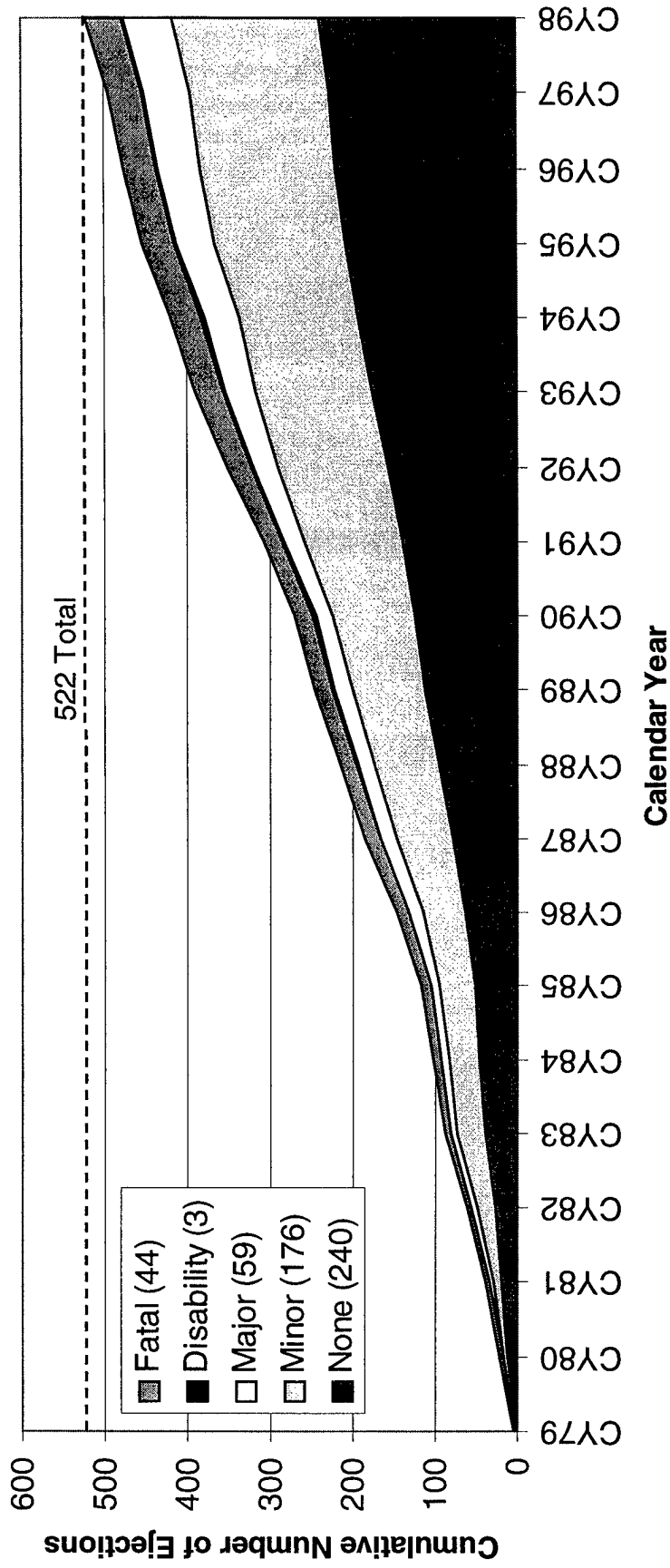


Notes: Time period examined for F/A-18 and F-14 from 1980; F-15 and F-16 from 1979. Seats include ACES-II for F-15 and F-16; GRU-7, SJU-5, and SJU-17 (NACES) for F-14 and F/A-18. Each ejection episode (where applicable) from two-seat model aircraft considered individually.

This chart displays the crew ejection history over the time period considered by the injury severity. Of the 522 ejection episodes reviewed, 44 resulted in fatal injuries, 3 resulted in a disability, 59 resulted in a major injury, 176 resulted in a minor injury, and 240 resulted in no reportable injuries. The first aid injuries for the Navy aircraft were merged with the no reportable injuries for consistency with the Air Force taxonomy.

Overall, there has been a relatively steady rate of each injury category over this time. The number of unsuccessful (fatality or disability) ejection incidents has averaged about 2 to 3 per year. For the aircraft combined, the number of unsuccessful ejection incidents (per seat) has been about 0.3 per 100,000 flying hours.

Crew Ejection History by Injury Severity



Notes: Time period examined for F/A-18 and F-14 from 1980; F-15 and F-16 from 1979. Seats include ACES-II for F-15 and F-16; GRU-7, SJU-5, and SJU-17 (NACES) for F-14 and F/A-18.
Each ejection episode (where applicable) from two-seat model aircraft considered individually.

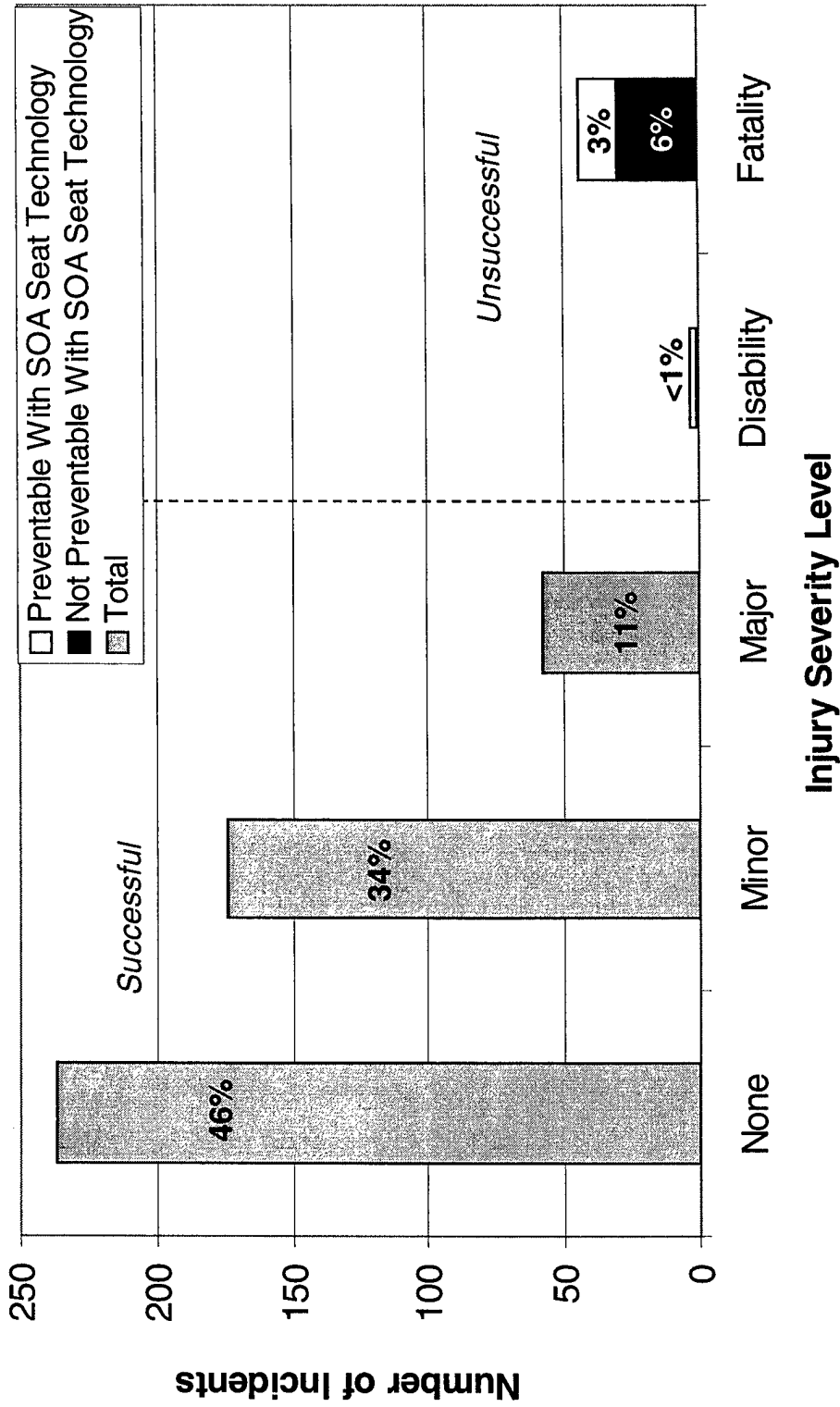
This chart displays the crew ejection injury distribution for the aircraft and time period considered in a bar chart format. The majority of aircrew members suffered either no reported injuries (46 percent) or minor injuries (34 percent). About 11 percent of the aircrew members sustained major injuries. Slightly less than 10 percent of the ejection incidents were unsuccessful.

Each of the unsuccessful incidents was examined individually to determine whether state-of-the-art seat technology could have prevented them. We considered design features on the K-36, such as the limb restraints, telescoping stability booms, flow deflector, and roll compensation, and the

Mk-16's Preplanned Product Improvement, such as the extremely fast drogue and parachute deployment times.

Based on the altitude, airspeed, and other relevant aircraft data (such as the roll and pitch angles and sink rate) at the point of ejection (where available), along with non-ejection seat factors (e.g., landing in the aircraft fireball, complications resulting from midair collisions, etc.), we estimated that about 3 percent of the unsuccessful ejections could have been potentially preventable with state-of-the-art seat technology. It is interesting to note that the most recently fielded ejection seat on U.S. tactical aircraft, the Navy NACES (on the F-14D and late-model F/A-18C/Ds), has had no unsuccessful ejection incidents (out of 26 total) to date.

Crew Ejection Injury Distribution

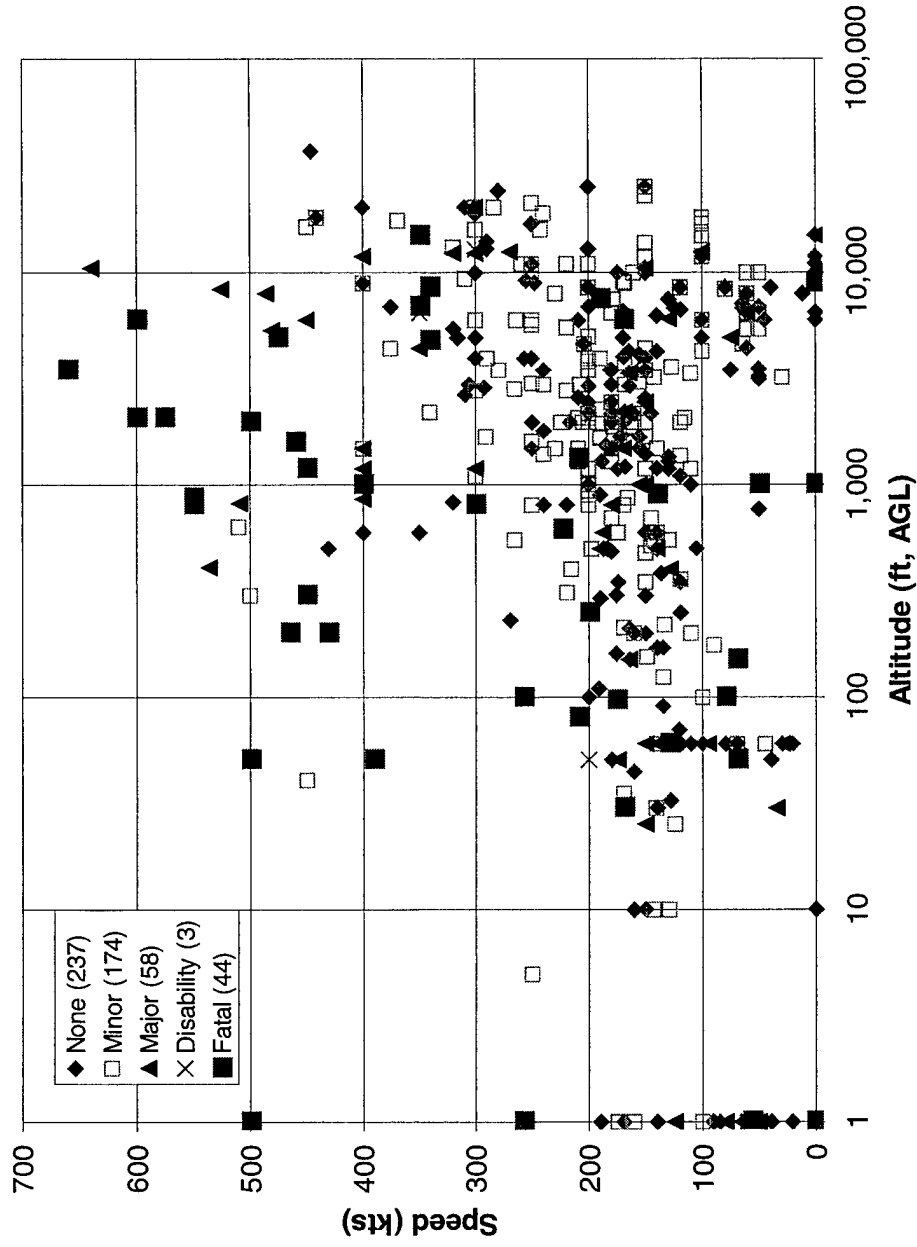


Note: Combined aircraft include ACES-II, GRU-7, SJU-5, and SJU-17 (NACES) seats.

This scatter plot displays the crew ejection flight conditions, in terms of speed and altitude, and the five injury category levels described previously. The altitude scale is shown in log-form for clarity and the ejection incidents that occurred at altitudes of zero were changed to one foot for display purposes. The speed and/or altitude were not known for 6 ejection incidents, so only 516 out of the 522 previously specified are shown.

Overall, there is a fairly wide scatter of the data points, but most are concentrated around speeds of 100 to 300 knots and altitudes of 1,000 to 10,000 feet. In this regime, most of the ejection injuries were either not reportable or minor. While there were relatively few ejection incidents above 400 knots, the fraction of fatal injuries in this region are notably higher. The frequency of fatal injuries appears to be also somewhat higher for ejection altitudes less than 100 feet.

Crew Ejection Experience by Flight Condition/Injury Category

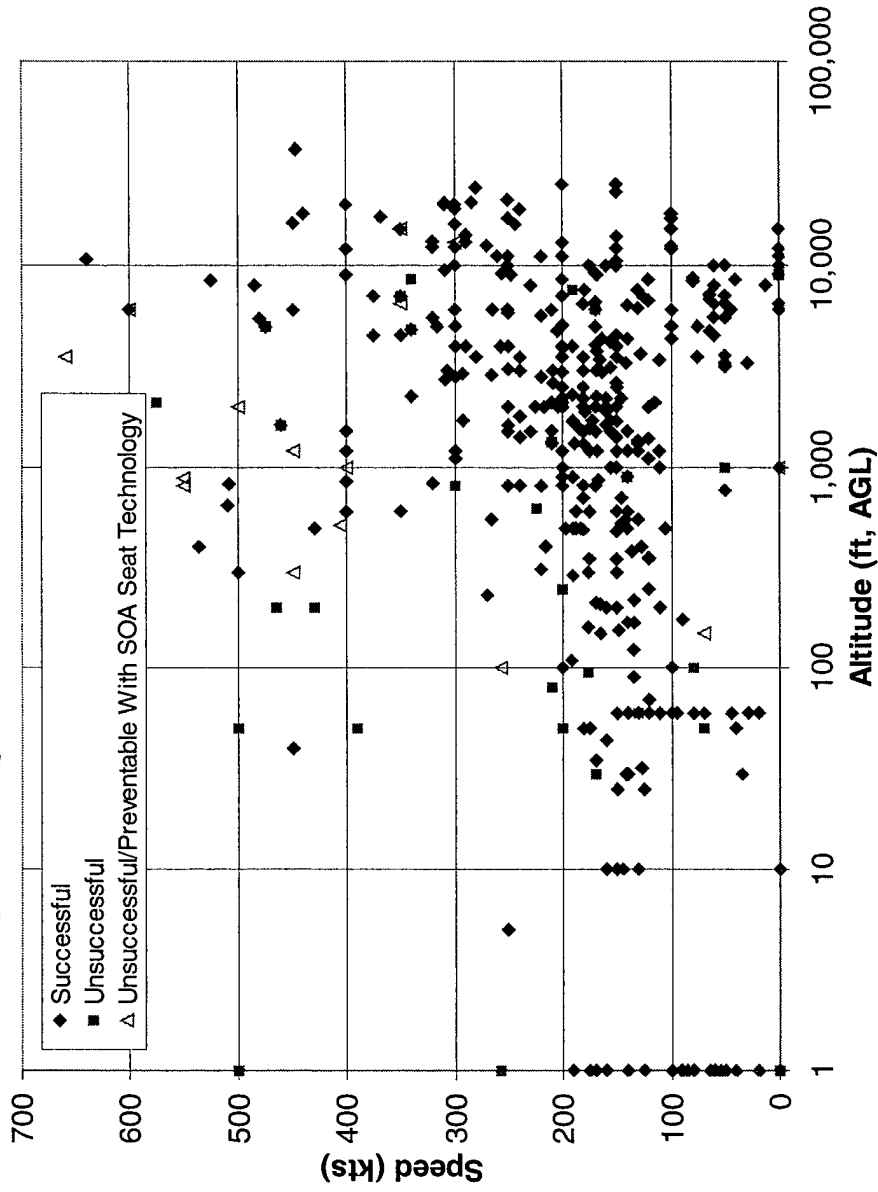


Notes: Zero-foot altitudes changed to one foot for log plotting purposes.
Speed and/or altitude not known for six incidents.

This slide depicts the crew ejection flight conditions, in terms of speed and altitude, with the success or failure scheme discussed previously. Also included in the scatter plot are the unsuccessful incidents that were deemed potentially preventable with state-of-the-art seat technology. The altitude scale is again shown in log-form for clarity and the ejection incidents occurring at altitudes of zero were changed to one foot for display purposes. The speed and/or altitude were again not known for 6 ejection incidents, so only 516 out of the 522 previously specified are shown.

This chart displays the same general trends as the previous chart, but adds the flight conditions for the unsuccessful incidents judged potentially preventable with state-of-the-art seat technology. While many of these points are scattered throughout the envelope, most occur where the ejection speed was in excess of 400 knots. Very few of these points occur for the ejection altitudes of 100 feet or less or greater than 10,000 feet.

Crew Ejection Success/Failure by Flight Conditions

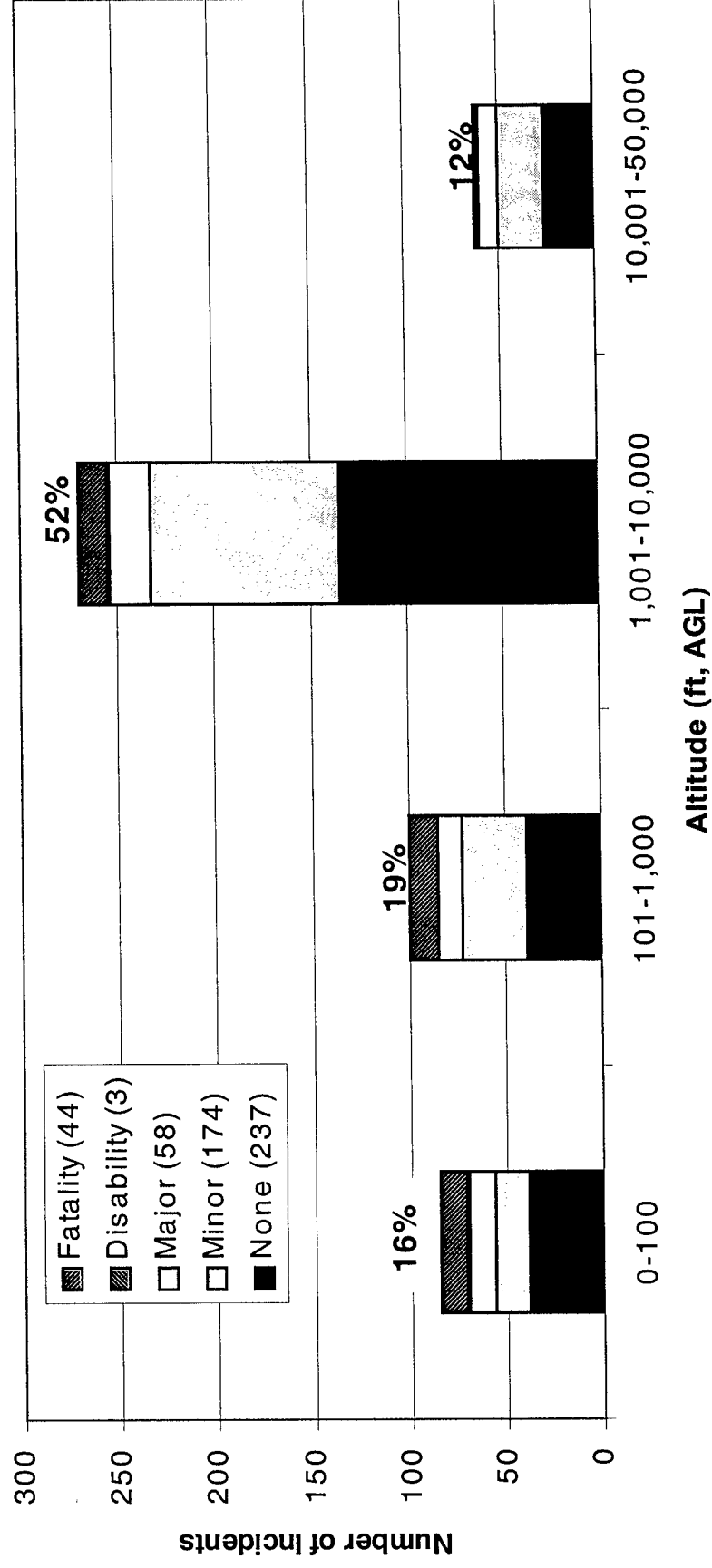


Notes: Zero-foot altitudes changed to one foot for log plotting purposes.
Speed and/or altitude not known for six incidents.

The distribution of aircrew ejection incidents and resulting injury categories by the aircraft altitude at the point of ejection is illustrated in this slide with a stacked bar chart. Four distinct altitude bands are used. The majority of the ejection incidents, 52 percent, occurred in the altitude range of 1,000 to 10,000

feet. The next most frequent altitude band where aircrew ejection happened was 101 to 1,000 feet, where 19 percent occurred. About 16 percent of the aircrew ejection incidents occurred between 0 and 100 feet. The least ejection incidents, 12 percent, were at altitudes of over 10,000 feet.

Crew Ejection Injury Categories by Aircraft Altitude



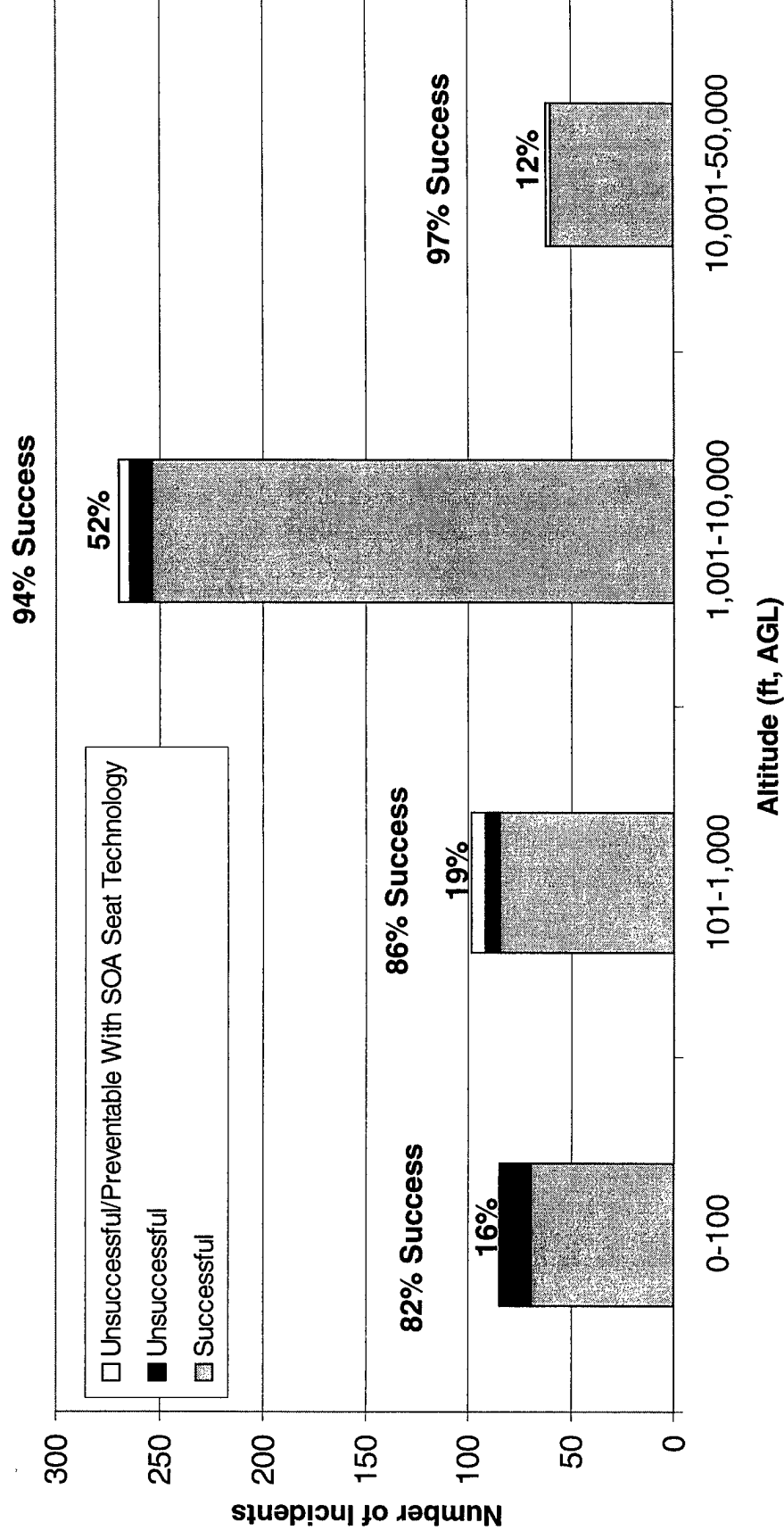
This slide depicts the distribution of aircrew ejection incidents by the aircraft altitude at the point of ejection for the success or failure scheme described previously. Also shown in the bar chart are the unsuccessful incidents that were deemed potentially preventable with state-of-the-art ejection seat technology.

The success rate observed increased with each of the four altitude bands used to parse the data. The lowest altitude band (0-100 feet) had a success rate of about 82 percent, while the highest band (above 10,000 feet) had a success rate of approximately 97 percent. The intermediate altitude bands

(101-1,000 feet and 1,001-10,000 feet) had success rates of 86 percent and 94 percent, respectively.

Most of unsuccessful incidents that were deemed potentially preventable with state-of-the-art seat technology occurred in the two middle altitude bands. In the 0-100 feet band, adverse attitude conditions or other factors negated any benefit of an improved seat. For the ejection incidents occurring at altitudes greater than 10,000 feet, very few were unsuccessful to begin with, making the potential benefits associated with new seat technology less compelling.

Crew Ejection Success/Failure by Aircraft Altitude

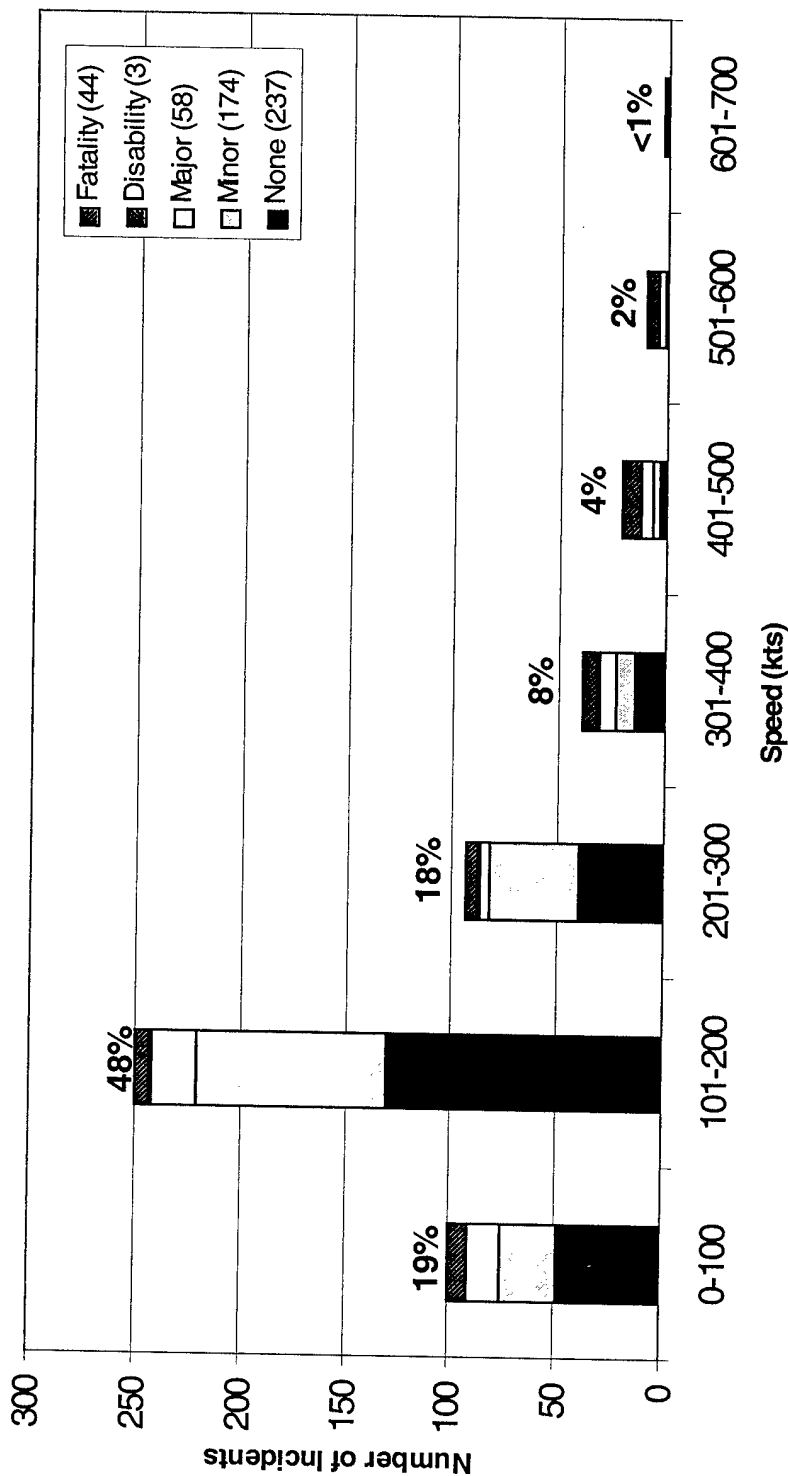


This slide illustrates in a bar chart the distribution of aircrew ejection incidents and resulting injury categories by the aircraft speed at the point of ejection. Seven distinct speed bands, measured in knots, are used. The majority of the ejection incidents, 48 percent, occurred in the 101- to 200-knot range. The next most frequent speed bands where aircrew ejection happened was the 0 to 100 range, where 19 percent occurred. In the 201- to 300-knot range, where 18 percent transpired, the number of aircrew ejection incidents are progressively lower with each higher speed band. Less than 3

percent of the aircrew ejection incidents happened at speeds in excess of 500 knots.

The overall average ejection speed from all the incidents observed was about 194 knots. The average ejection speed significantly increases with the severity of the injury category. For the no reportable injuries category, the average ejection speed was only 169 knots. For the minor and major injury categories, the average ejection speeds were 188 and 229 knots, respectively. Disabilities or fatalities were much higher at average ejection speeds of 283 and 304 knots, respectively.

Crew Ejection Injury Categories by Aircraft Speed



Notes: Average overall ejection speed (kts) = 194 knots. Average speed by injury category: None = 169 knots, Minor = 188 knots, Major = 229 knots, Disability = 283 knots, Fatality = 304 knots.

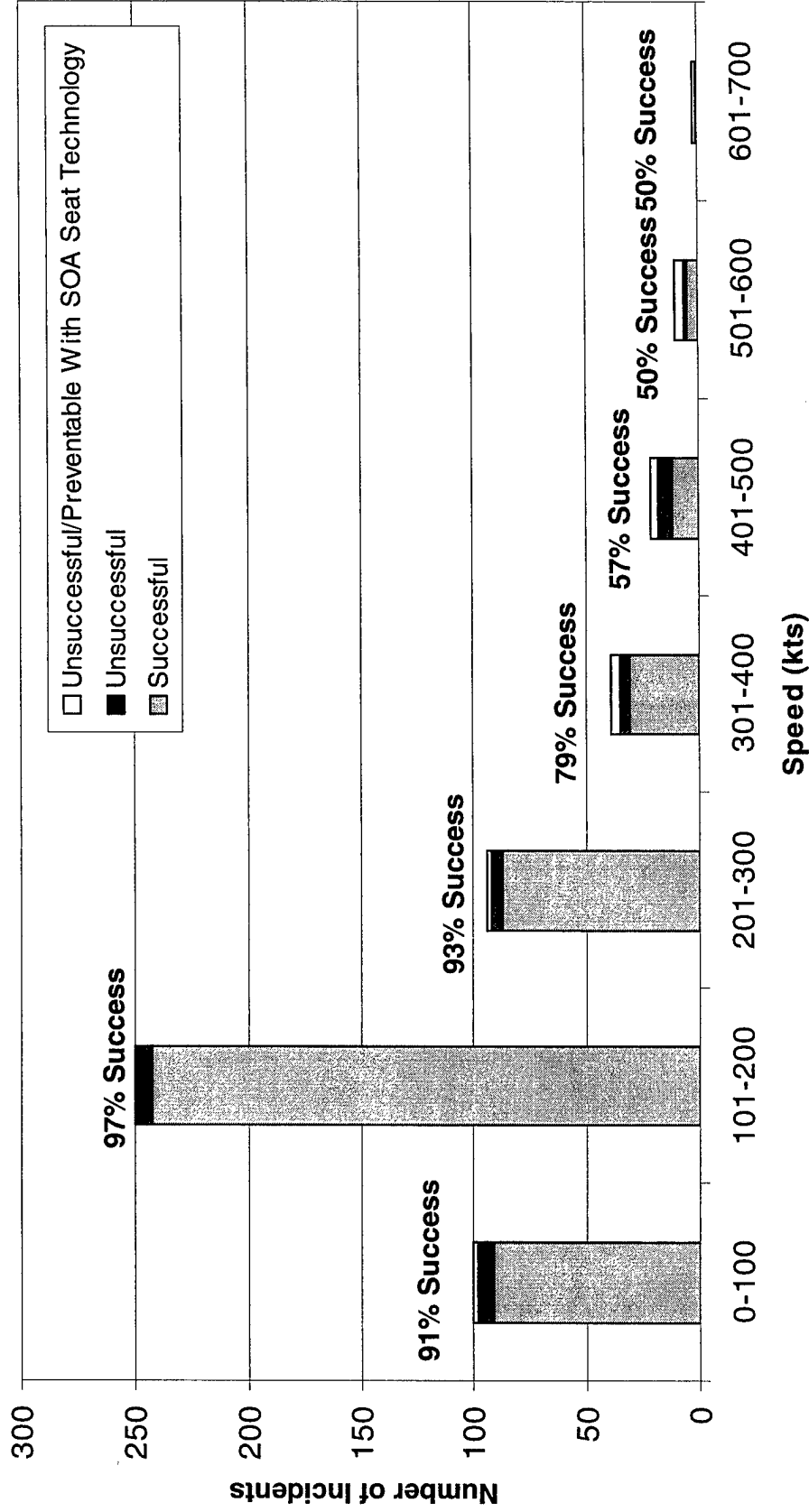
The distribution of aircrew ejection incidents with the success or failure scheme described previously by the aircraft speed is shown here. We included the unsuccessful incidents that were deemed potentially preventable with state-of-the-art ejection seat technology.

The success rate observed initially increased then dramatically decreased with speed. The lowest speed band (0-100 knots) had a success rate of about 91 percent. The ejection success rate was highest, approximately 97 percent, within the range of 101 to 200 knots. At the third (201-300 knots) speed range, the success rate was about 93 percent. At higher speeds, the success rate decreased to 79 percent, then 57 percent,

eventually reaching a minimum of approximately 50 percent at speeds in excess of 500 knots.

The average overall ejection speed from all the incidents observed was about 194 knots. For the successful and all unsuccessful aircrew ejection incidents, the average speed was roughly 183 knots and 302 knots, respectively. The average speed for the unsuccessful incidents that were deemed preventable with state-of-the-art seat technology was very high, about 406 knots. The average speed for the unsuccessful incidents that were not judged to be preventable with state-of-the-art seat technology was 250 knots.

Crew Ejection Success/Failure by Aircraft Speed



Notes: Average successful/unsuccessful (overall) speeds = 183/302 knots. Average unsuccessful/not preventable with SOA seat technology speed = 250 knots. Average unsuccessful/preventable with SOA seat technology speed = 406 knots.

This chart presents the combined crew-ejection success rates (and number of incidents) in a table by the speed and altitude ranges used previously. Ejection incidents with the conditions associated with the values in the lower right area have generated the highest success rates. In the four boxes in

this corner, the success rates range from 98 to 100 percent from a total of 188 individual cases. The upper left region represents conditions that have resulted in low ejection success rates. While less frequent, the six boxes in this corner account for 12 ejection events with an average success rate of only 50 percent.

Combined Crew Ejection Success Rates at Various Flight Conditions (Number of Incidents)

Speed (knots)	Altitude (ft, AGL)				
	1-10	11-100	101-1,000	1,001-10,000	10,000-50,000
601-700	0% (0)	0% (0)	0% (0)	0% (1)	100% (1)
501-600	0% (0)	0% (0)	60% (5)	40% (5)	0% (0)
401-500	0% (0)	50% (2)	40% (5)	56% (9)	100% (4)
301-400	0% (0)	0% (1)	67% (6)	83% (23)	89% (9)
201-300	50% (2)	0% (2)	78% (9)	98% (57)	96% (24)
101-200	100% (10)	85% (26)	97% (68)	98% (133)	100% (13)
0-100	91% (22)	84% (19)	50% (6)	98% (42)	100% (0)

The incidents examined in this briefing occurred during peacetime. No combat ejection episodes, such as the F-16 event (pilot Scott O'Grady) during Deliberate Force or the F-117 and F-16 incidents during Allied Force, were included. Ejection incidents during combat may occur with a different pattern of flight conditions (altitude and speed) and may result in different injury spectra than we have shown.

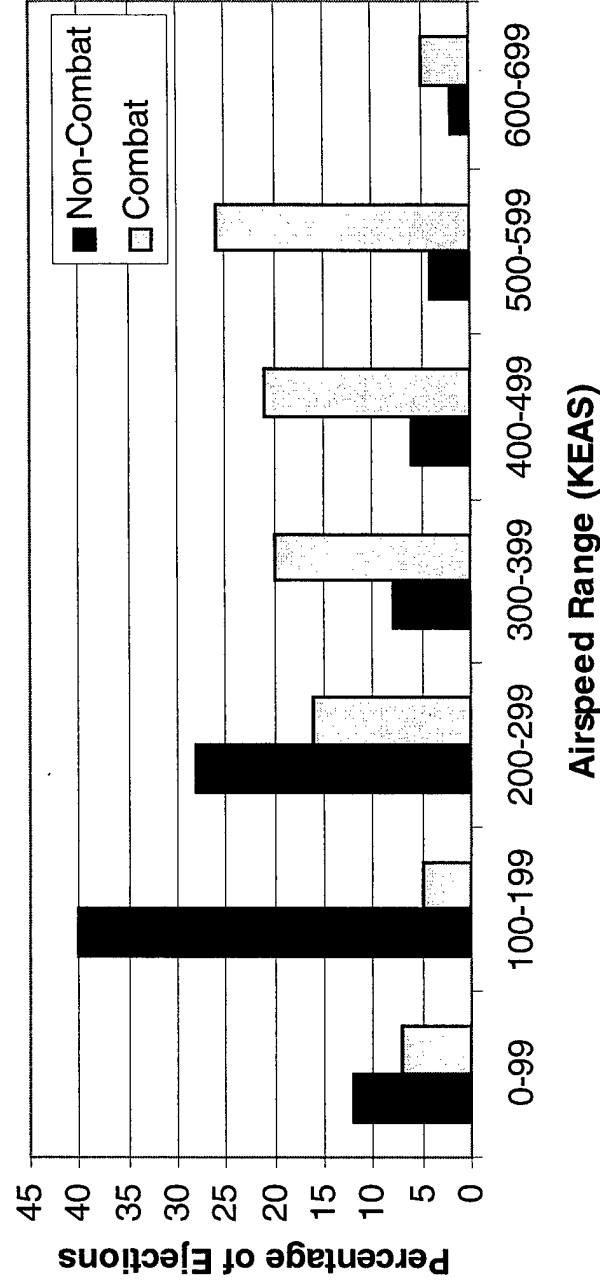
This slide displays the percentage of ejection incidents by speed for 390 ACES-II non-combat ejections overlaid with 170 combat ejections in Southeast Asia from 1963 to 1971. The data for the chart are from the Air Force Research Laboratory (AFRL). The ejection speeds during this combat period are notably higher than those observed during peacetime, by an

average of over 150 knots. Over 50 percent of the combat ejection incidents occurred at speeds in excess of 400 knots, as opposed to only 12 percent during the peacetime period. The resulting injury spectra of the combat ejection episodes are not known.

It is important to note that ejection injuries sustained in a combat environment may be of more significance than those suffered in peacetime. Historically, ejection injuries have hampered aircrew rescues, contributed to higher aircrew capture rates, and, in some instances, resulted in the loss of rescue helicopters and crews. Consequently, the previously defined measure of ejection success (major injury or less) may be reduced to only minor injuries or less in combat situations.

Combat/Non-Combat Crew Ejection Speeds

390 ACES-II non-combat ejections as of February 1998
170 Southeast Asia combat ejections from 1963-1971



Source: Air Force Research Laboratory.

Notes: Injuries sustained in combat ejection incidents have hampered aircrew rescues, contributed to higher aircrew capture rates resulting in POWs, and resulted in loss of rescue helicopters and crews.

The initial observations from our examination are summarized in this chart.

The overall success rate with existing ejection seats on current U.S. fighter aircraft is about 90 percent. While this is a remarkable achievement given the often demanding escape environment scenarios and ejection seat design challenges, the unsuccessful rate of 10 percent should be reduced in the future if possible. It is interesting to note that few of the ejection incidents examined (3 out of 522) resulted in permanent

disability injuries; most of the unsuccessful ejections were fatalities.

With state-of the-art ejection seat technology, a small number of the unsuccessful incidents observed could have been prevented. With state-of-the-art technology, the severity of other injuries could have been reduced as well. These technologies are incorporated in the Russian K-36, some are on the current or planned for the improved Boeing ACES-II and Martin-Baker NACES/Mk-16 seats.

Initial Observations

- **Overall peacetime success rate (no fatalities or disabilities) with existing ejection seats on U.S. F-16, F-15, F/A-18, and F-14 fighter aircraft is about 90 percent**
 - **Unsuccessful 10 percent should be reduced if possible**
 - **Few of the ejection incidents examined (3 of 522) resulted in permanent disability injuries**
- **With state-of-the-art ejection seat technology, a small number of the unsuccessful incidents could have been prevented**
 - **Severity of other injuries could have been reduced**
 - **Technologies now incorporated in Russian K-36; some on or planned for the Boeing ACES-II and Martin-Baker NACES/Mk-16 seats**

Few of the ejection incidents examined occurred from the fighter aircraft flying at speeds above 500 knots. This appears to represent the typical pattern for peacetime. Data for a number of aircraft with drastically different speed capabilities (e.g., the A-10 and F-16) show no difference in the average aircraft speed at the point of ejection. The F-22A will have

super-cruise capability. It is unknown whether this will impact the average ejection speed from this aircraft. Historically, combat ejections have occurred at much higher speeds. Data from AFRL suggest an average difference of about 165 knots, with more than 50 percent of crew ejections in combat occurring at speeds in excess of 400 KEAS.

Initial Observations (Continued)

- **Few ejection incidents have occurred from these U.S. fighter aircraft above 500 knots**
 - **USAF combat ejections occurred at higher speeds (average difference of about 165 knots); more than 50 percent of pilot ejections in combat (from AFRL data) occurred at over 400 KEAS**
 - **Peacetime ejection speeds are not a function of aircraft performance (e.g., A-10 vs. F-16)**
 - **F-22A will have supercruise capability; does it matter?**

The ejection seat is only one of myriad safety features on a fighter aircraft. Improvements to it should be considered as one option in a portfolio of possible safety enhancements. For example, results from a recent IDA study suggests that an automatic ground collision avoidance system (AGCAS) for the

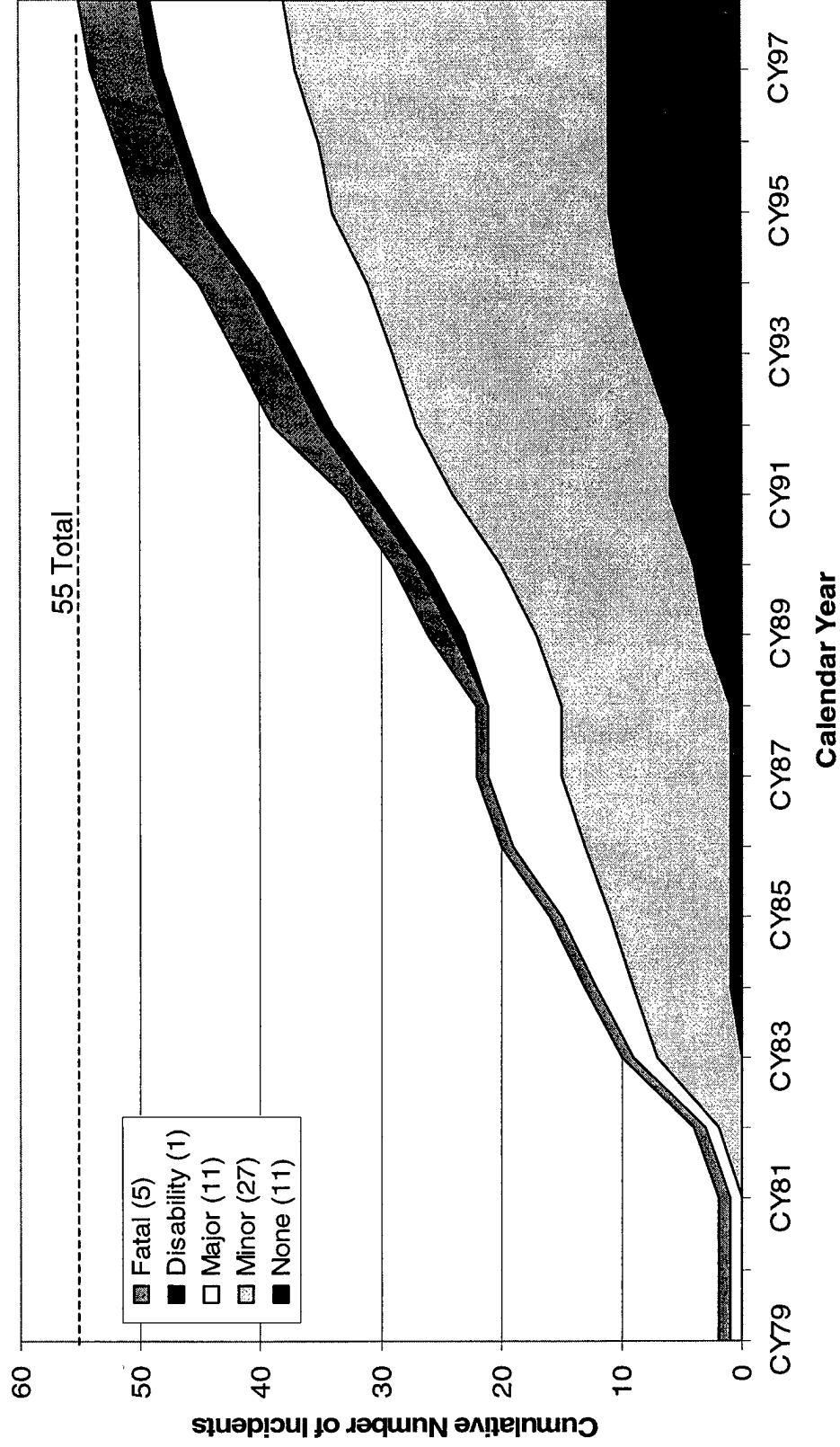
F-22A would provide a greater safety benefit at less cost than a new ejection seat for the aircraft. However, at a minimum, modifications to existing seats will be necessary to accommodate wider aircrew weight ranges without adding to the risk of ejection.

Conclusion

- **Ejection seat is only one safety feature; should be considered as one option in portfolio of possible safety enhancements**
- **At a minimum, modifications to existing seats will be necessary to accommodate wider aircrew weight ranges without additional ejection risk**

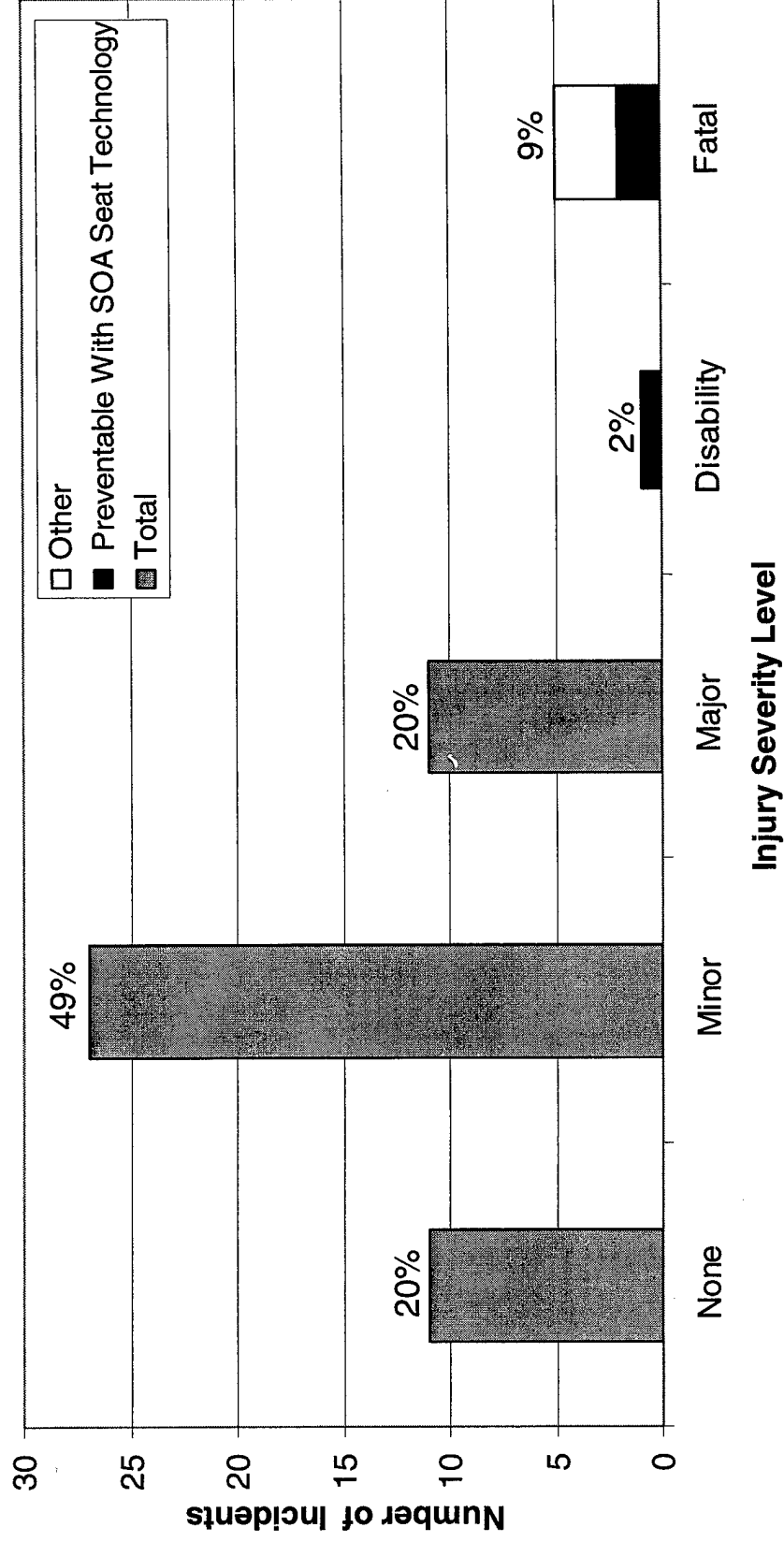
APPENDIX A
SUPPORTING SLIDES

F-15 Crew Ejection History (ACES-II Only)

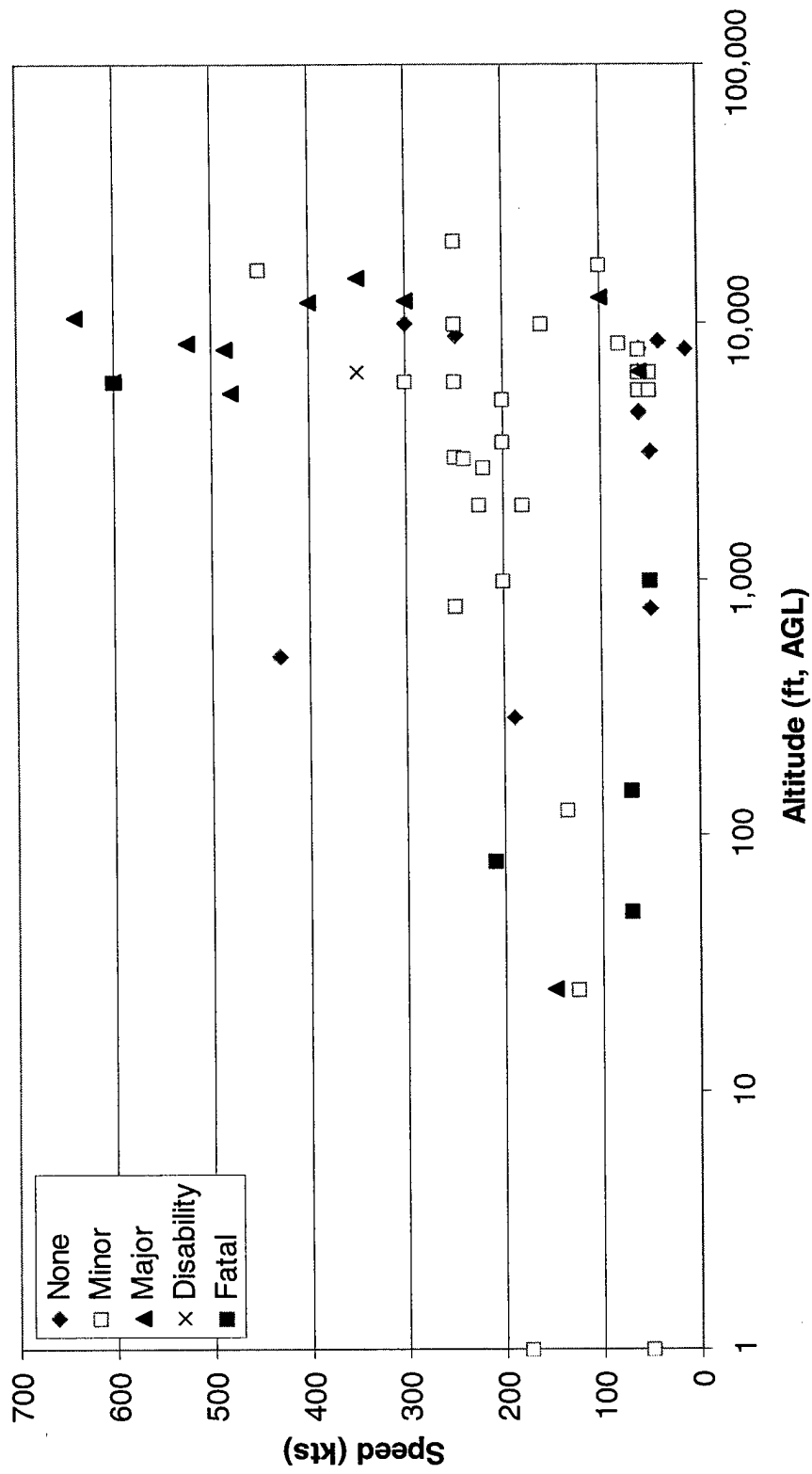


Note: Historical ejection rate since 1979 = 1.5 per 100K FH.

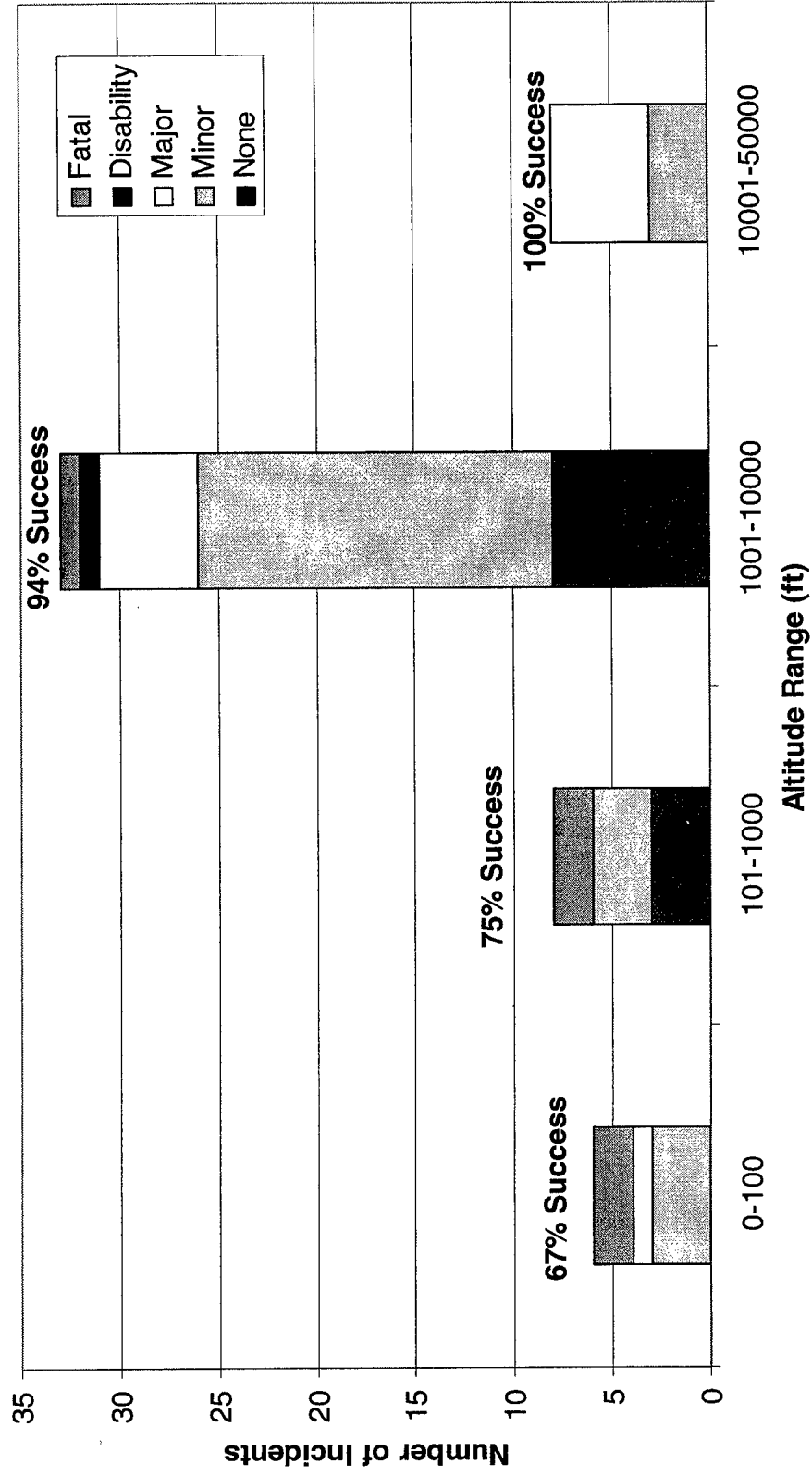
F-15 Crew Ejection Injury Distribution



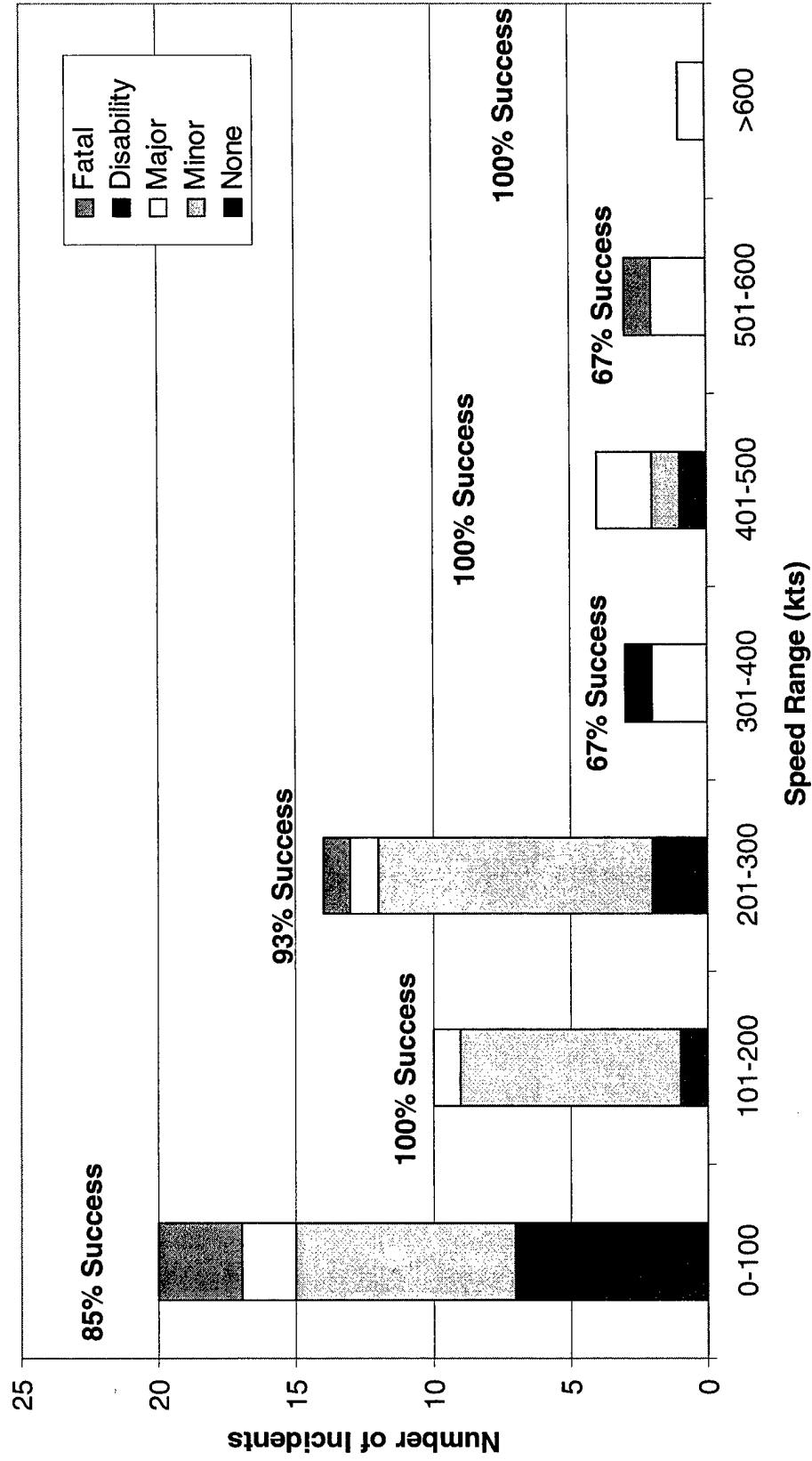
F-15 Crew Ejection Flight Condition/ Injury Category Experience



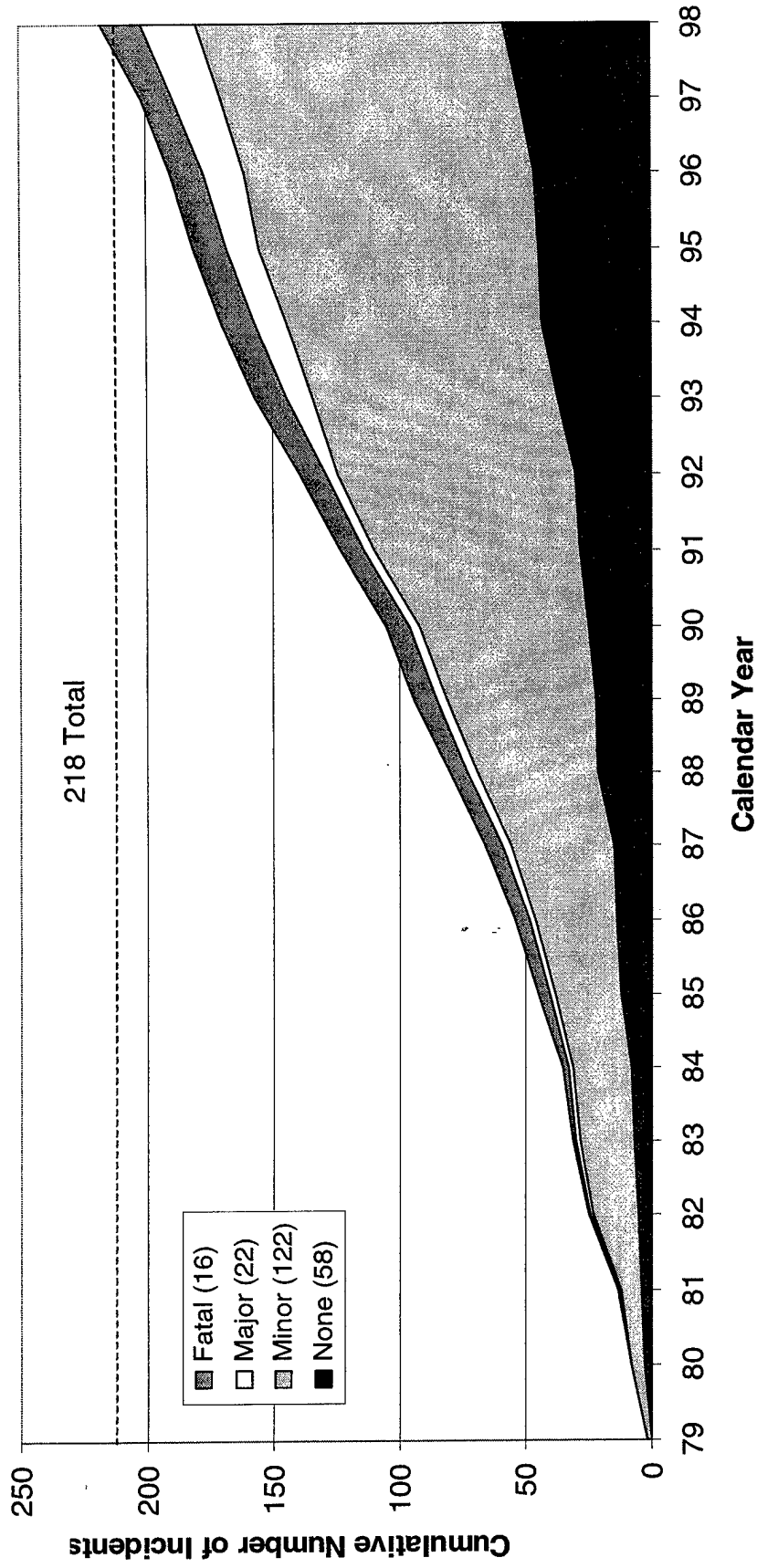
F-15 Crew Ejection Altitude Distribution



F-15 Crew Ejection Speed Distribution

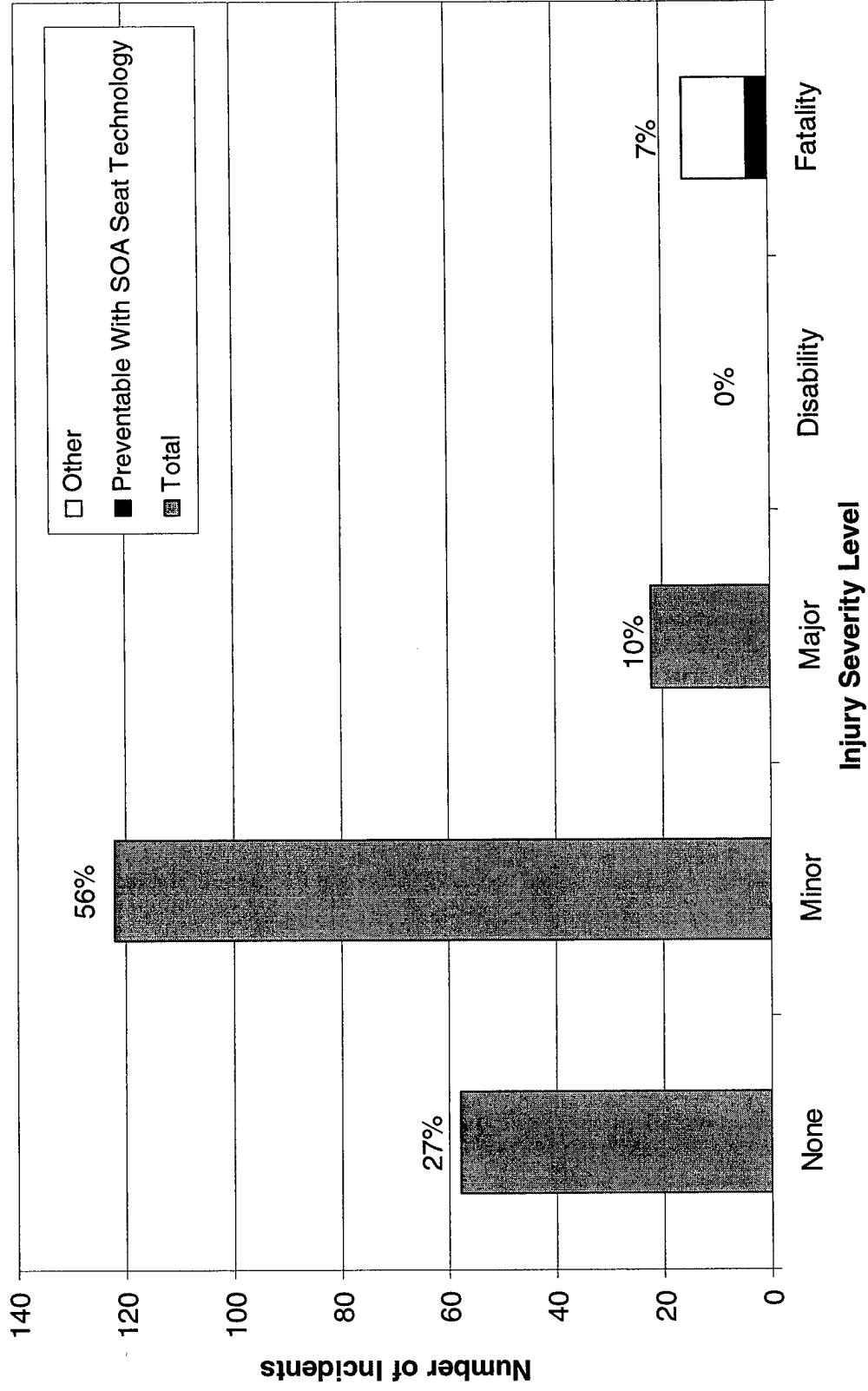


F-16 Crew Ejection History

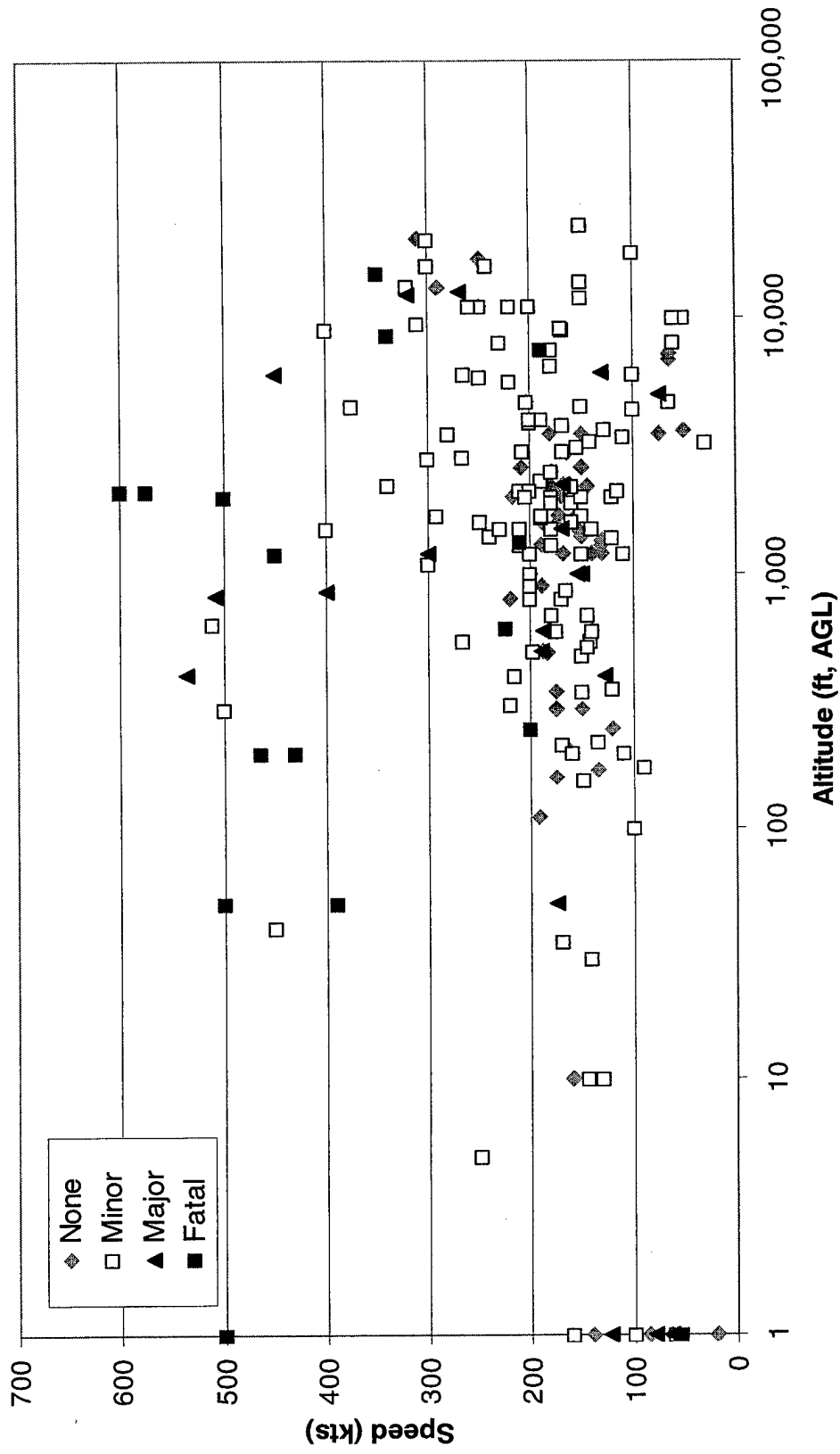


Note: Historical ejection rate since 1979 = 3.9 per 100K FH.

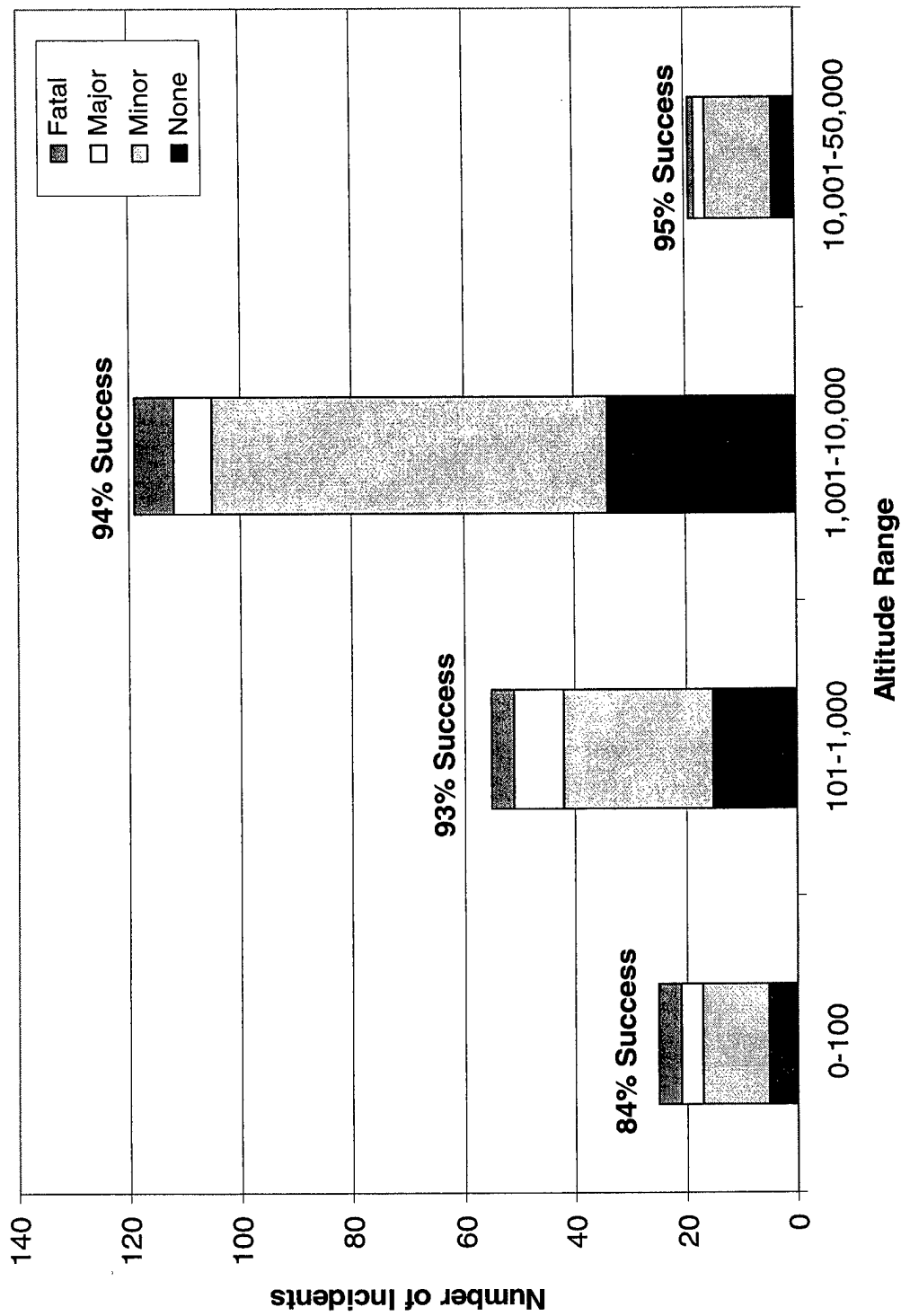
F-16 Crew Ejection Injury Distribution



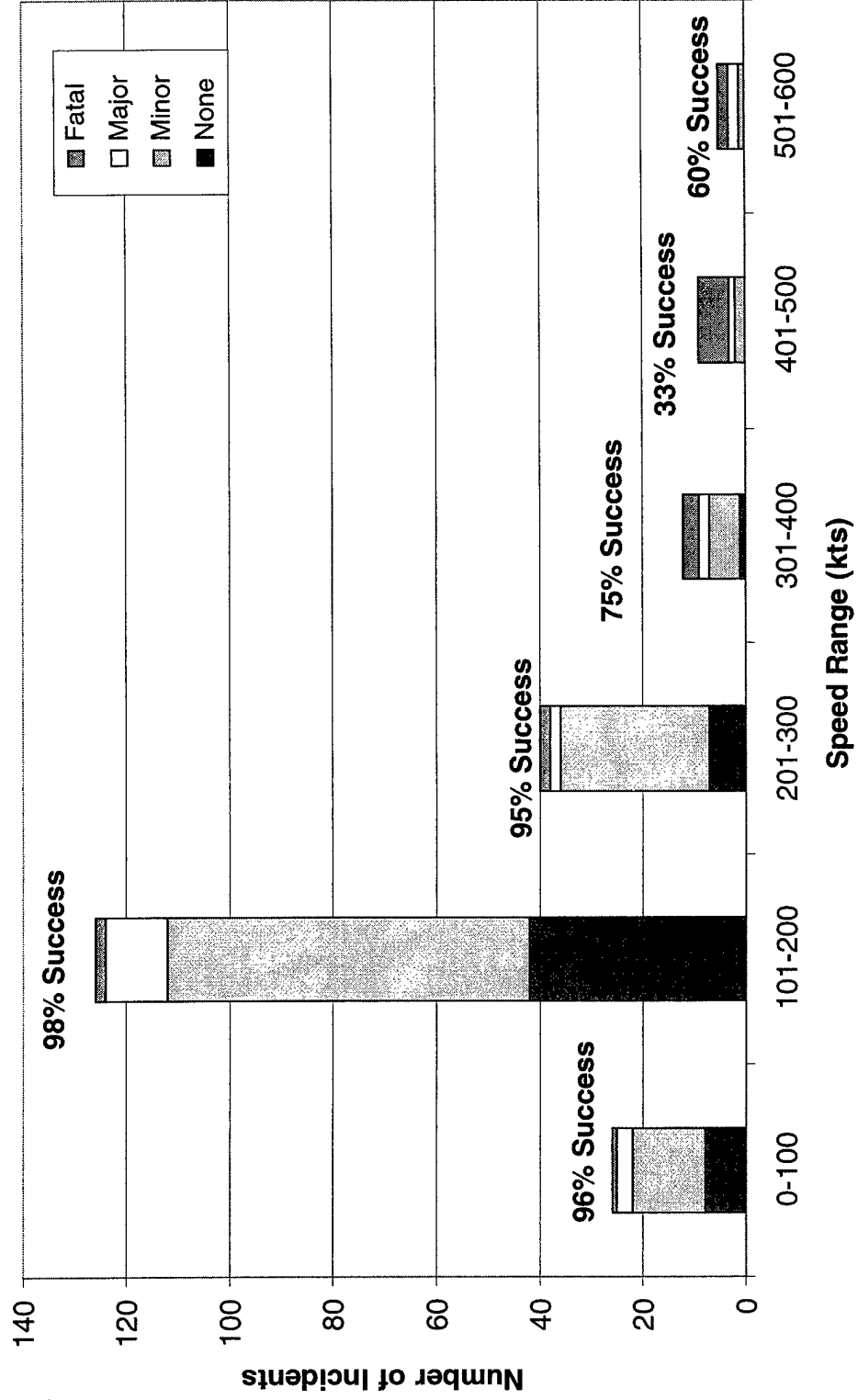
F-16 Crew Ejection Flight Condition/ Injury Category Experience



F-16 Crew Ejection Altitude Distribution



F-16 Crew Ejection Speed Distribution

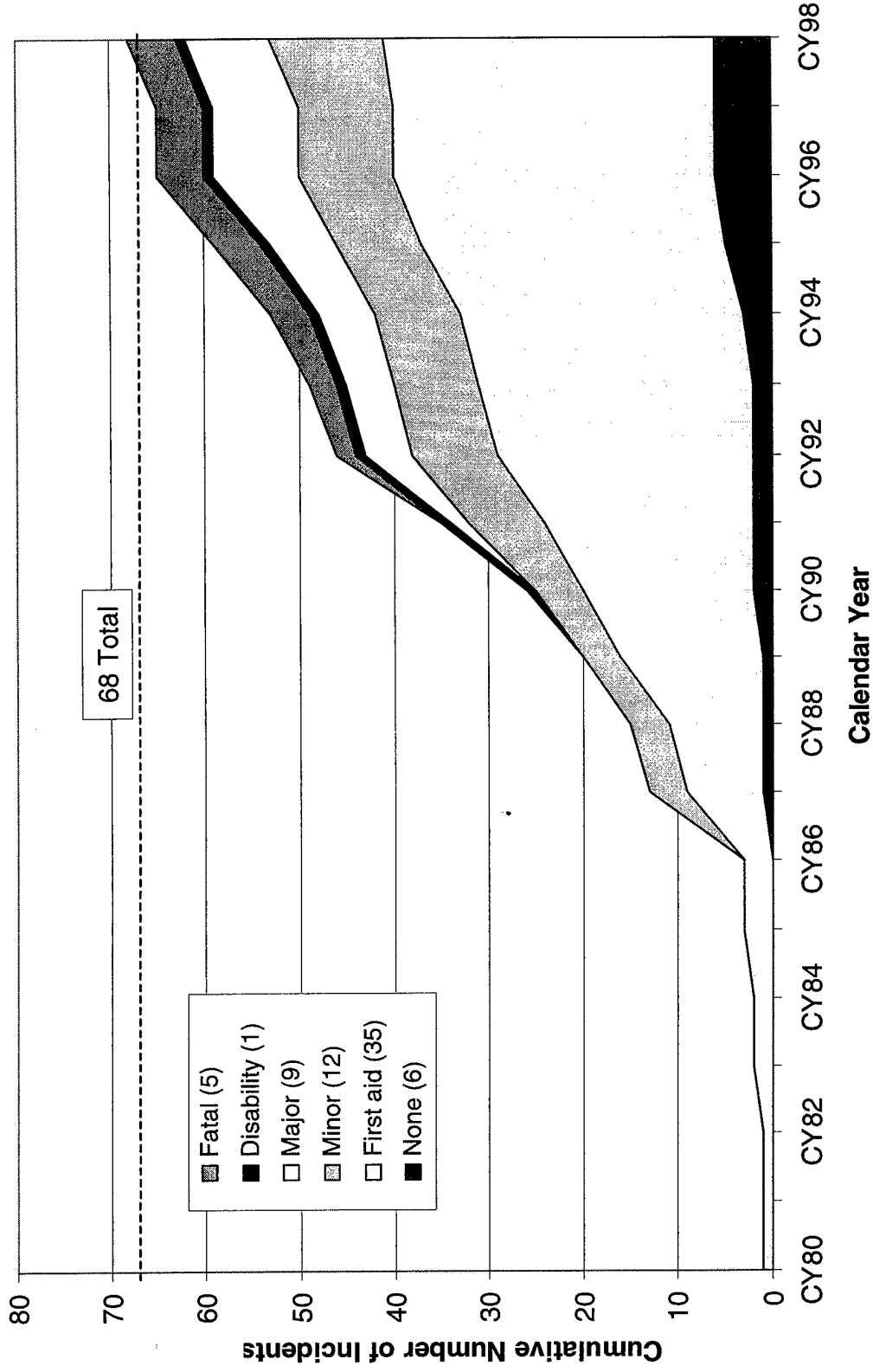


F/A-18 and F-14 Ejection Seats

Aircraft	Ejection Seat Model		
	GRU-7 (Mk-7)	SJU-5 (Mk-10)	SJU-17 NACES (Mk-14)
F/A-18A		X	
F/A-18B		X	
F/A-18C		Some	Some
F/A-18D		Some	Some
F/A-18E			X
F/A-18F			X
F-14A	X		
F-14B	X		
F-14D			X

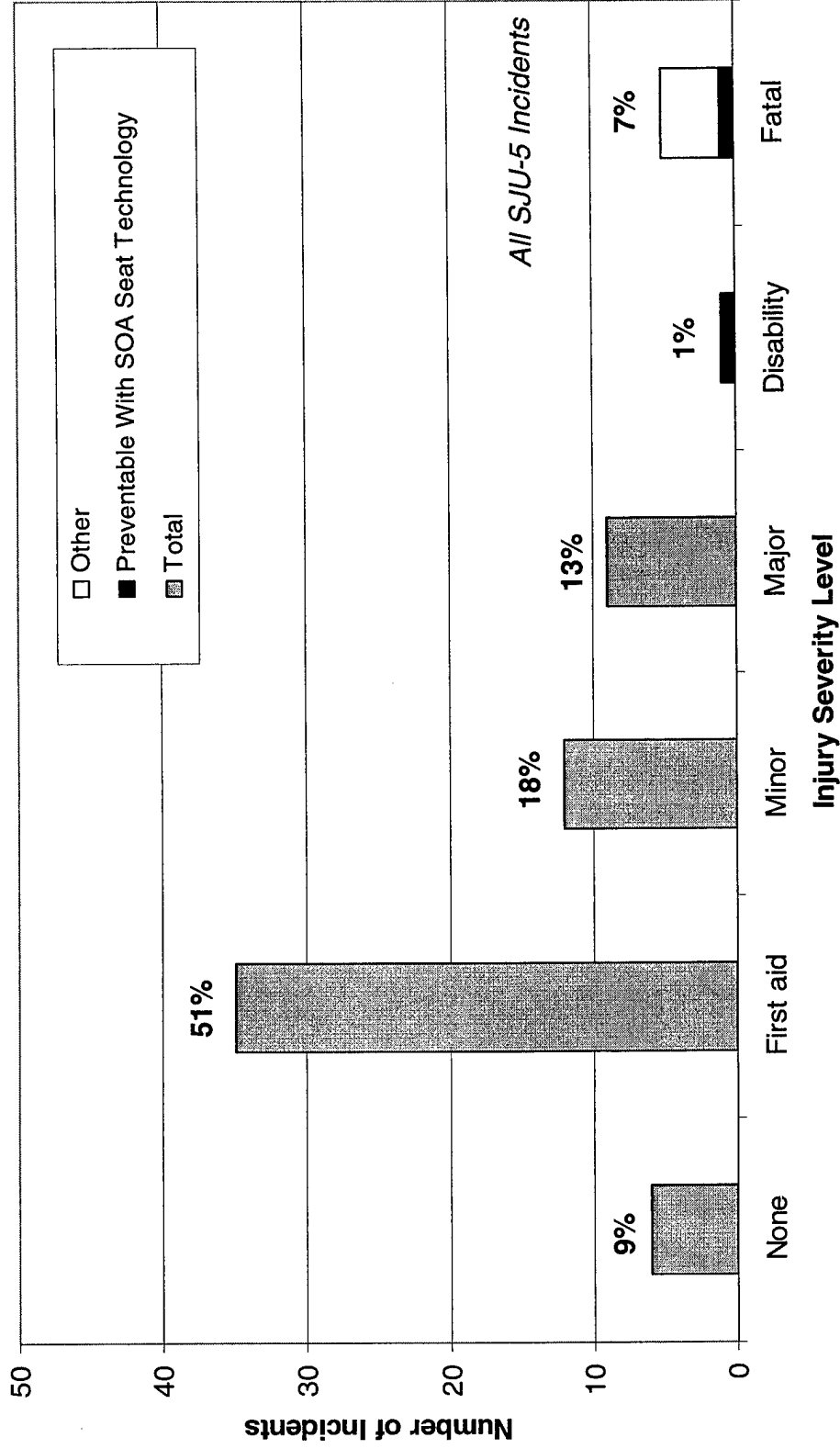
Note: All seats manufactured by Martin-Baker.

F/A-18 Crew Ejection History (From 1980)



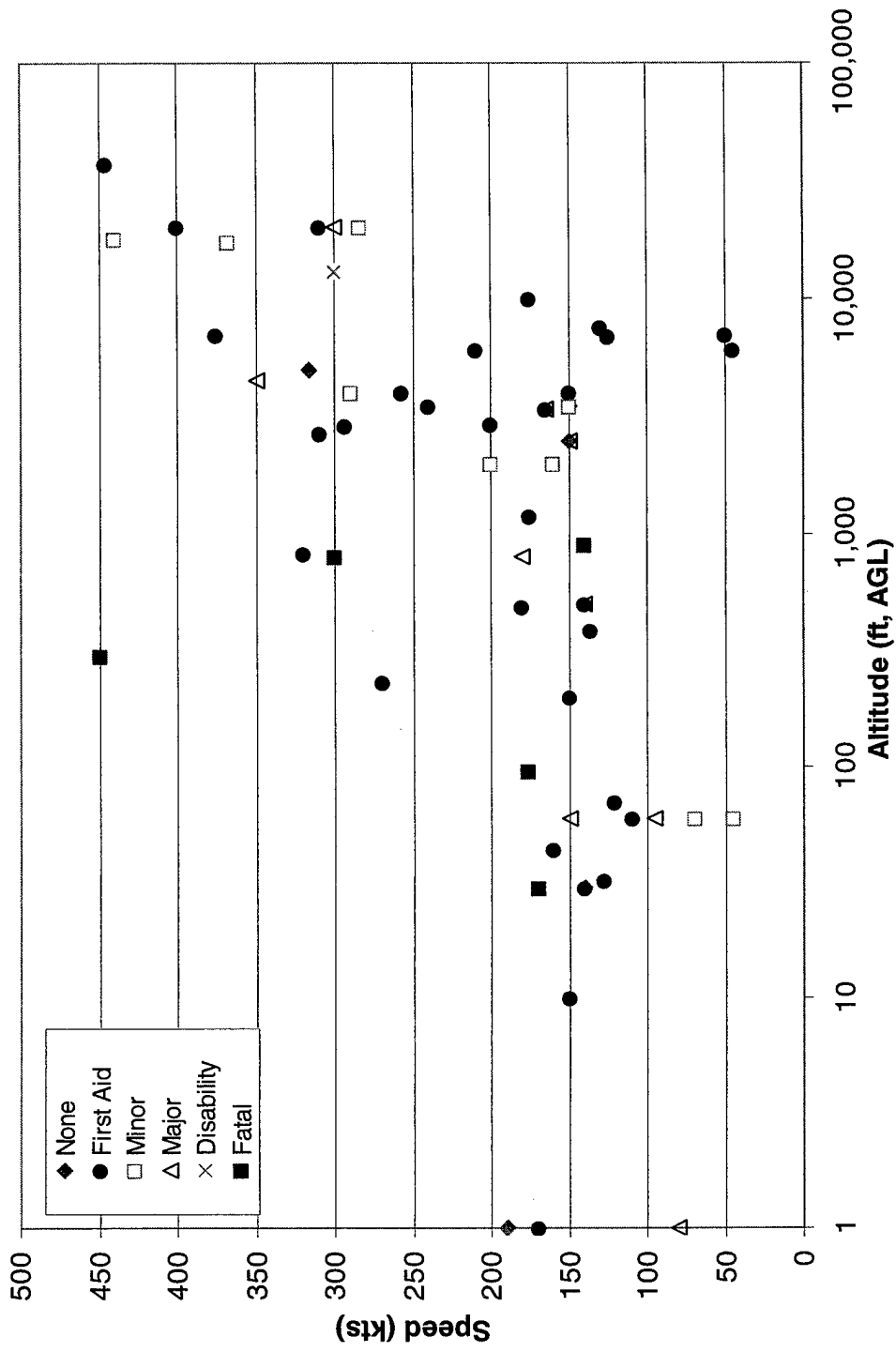
Note: Historical ejection rate since 1980 = 2.2 per 100K FH.

F/A-18 Crew Ejection Injury Distribution

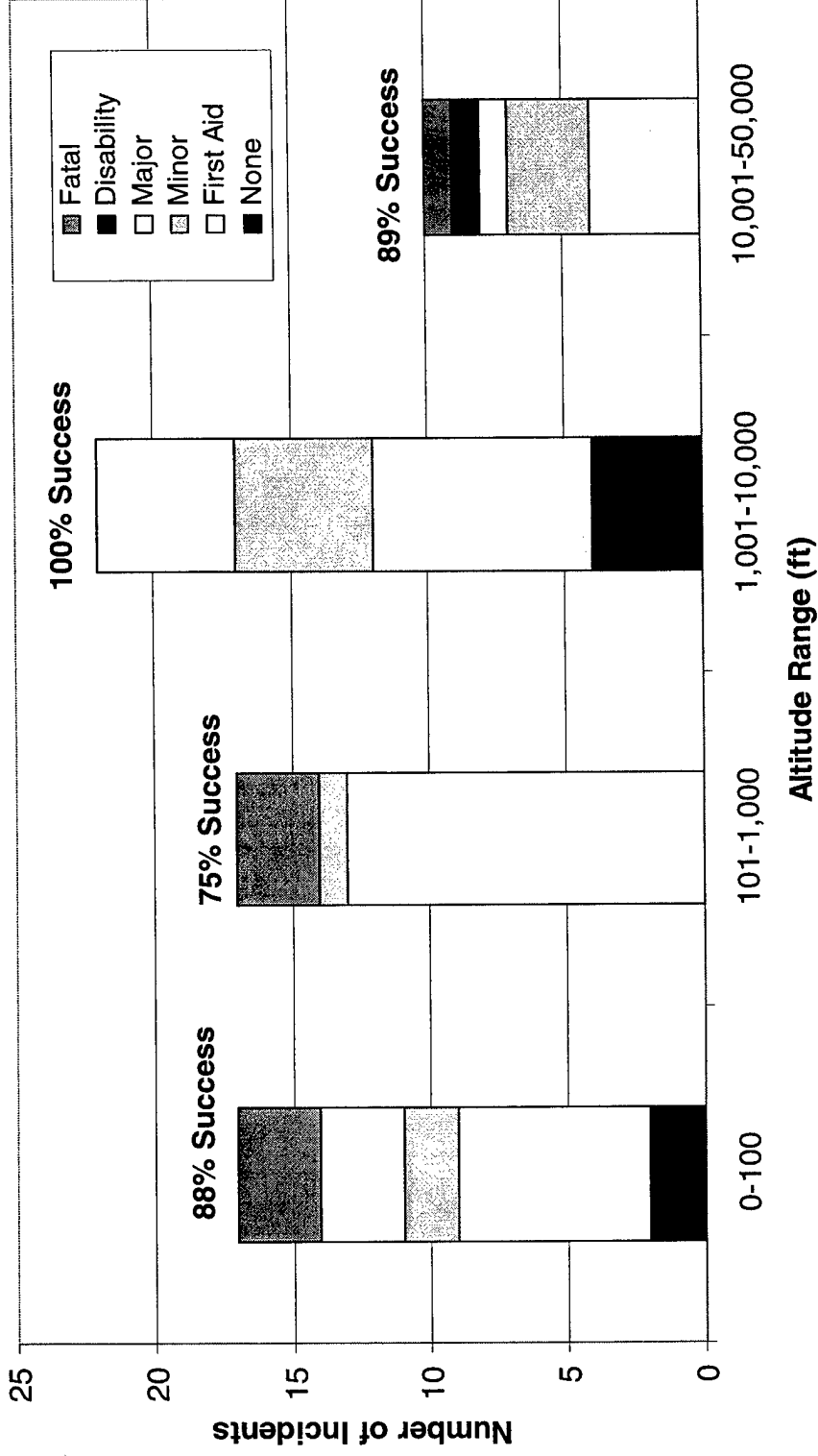


Note: SJU-5 and SJU-17 NACES ejection seats used.

F/A-18 Crew Ejection Flight Condition/Injury Category Experience

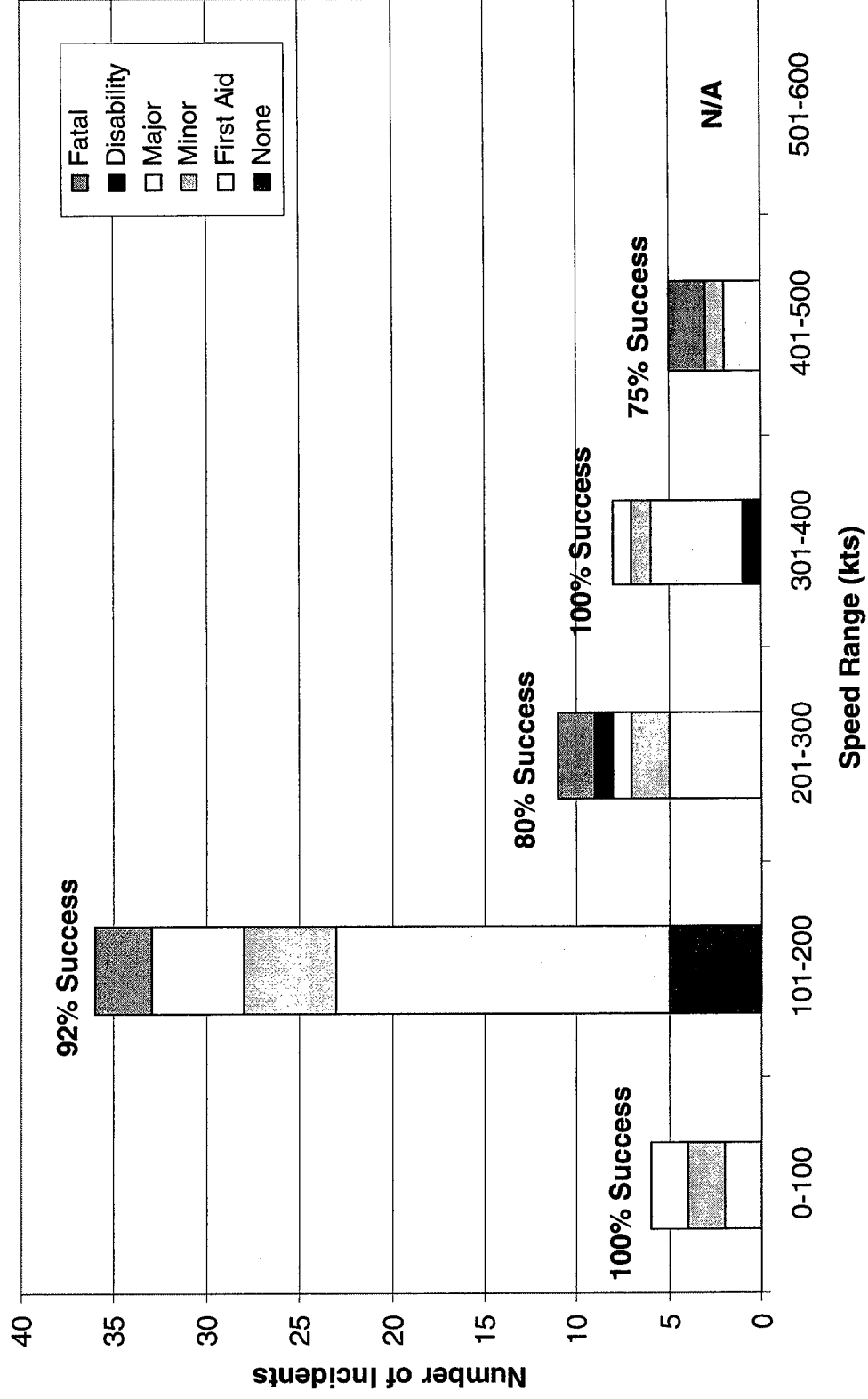


F/A-18 Crew Ejection Altitude Distribution



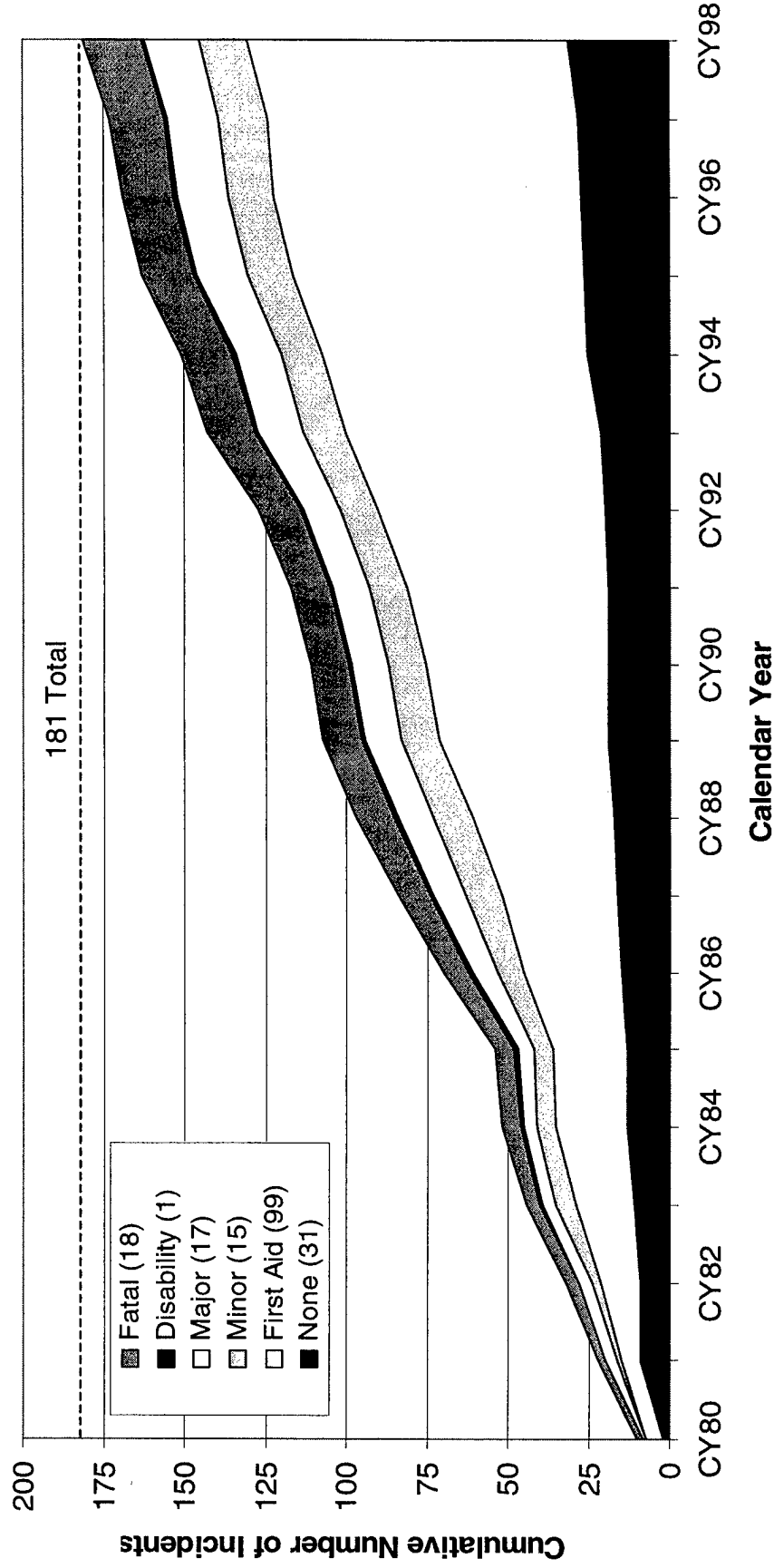
Note: Environment not known for four ejections.

F/A-18 Crew Ejection Speed Distribution



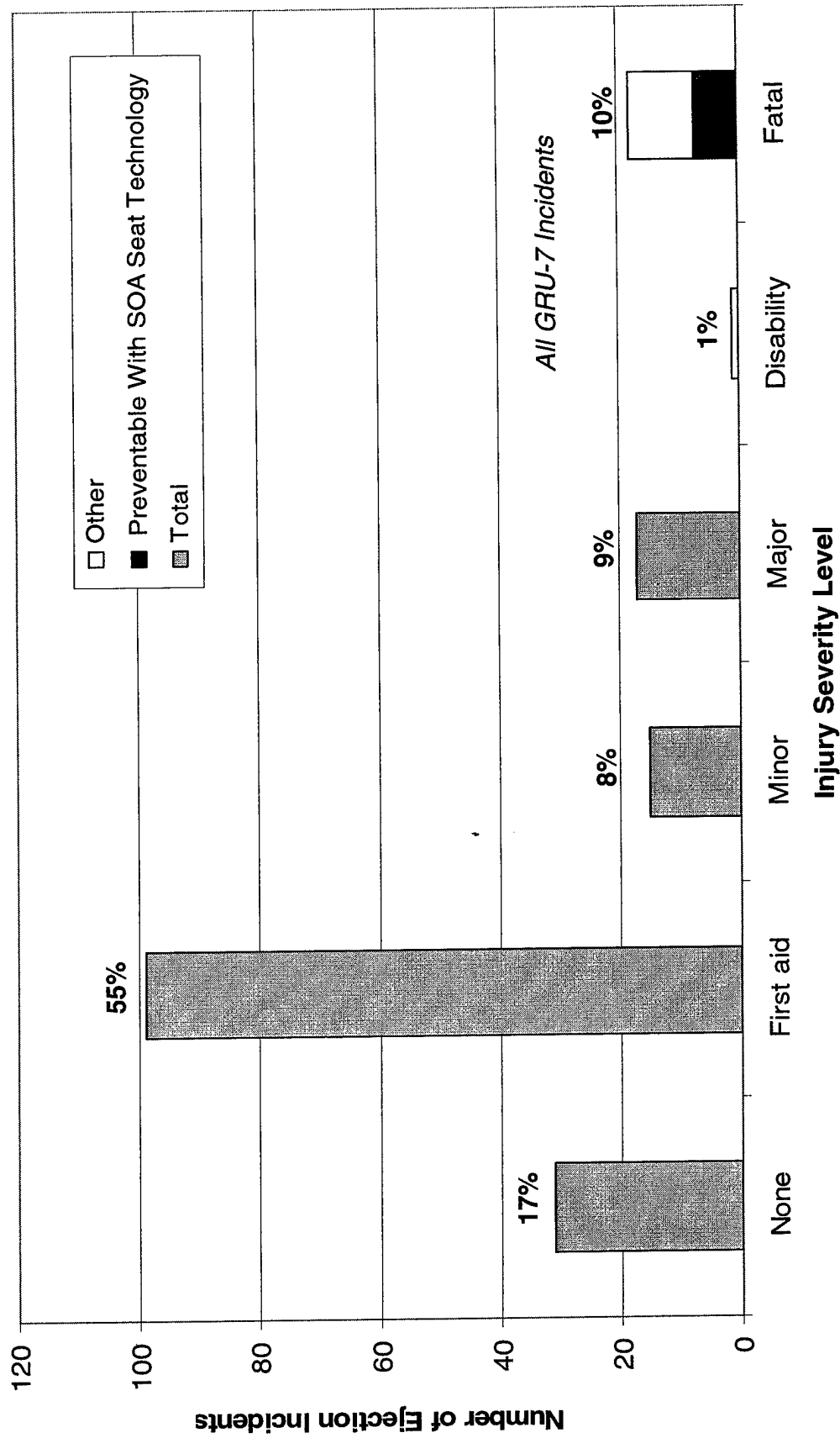
Note: Environment not known for four ejections.

F-14 Crew Ejection History (from 1980)



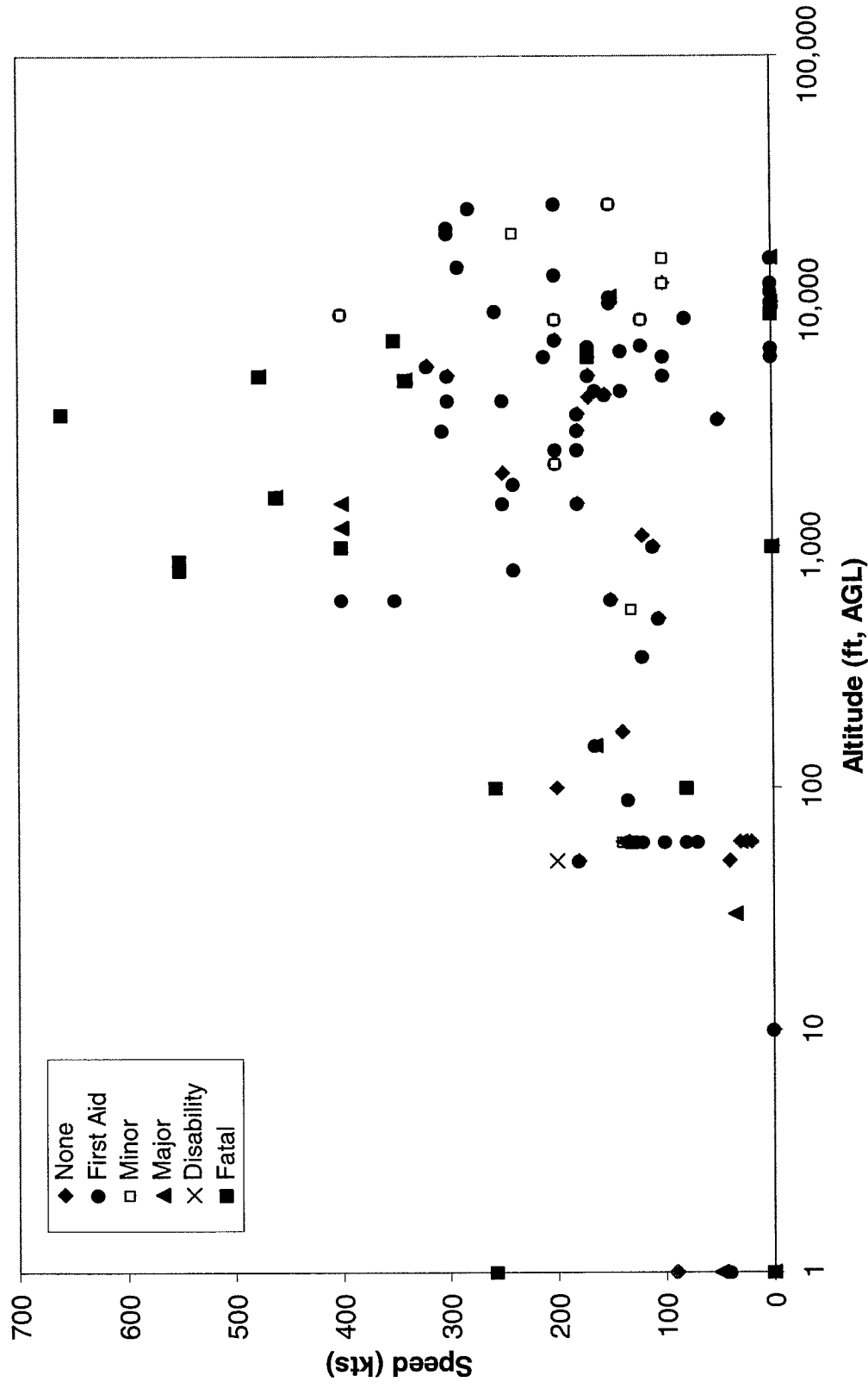
Note: Historical ejection rate since 1980 = 9.5 per 100K FH.

F-14 Crew Ejection Injury Distribution



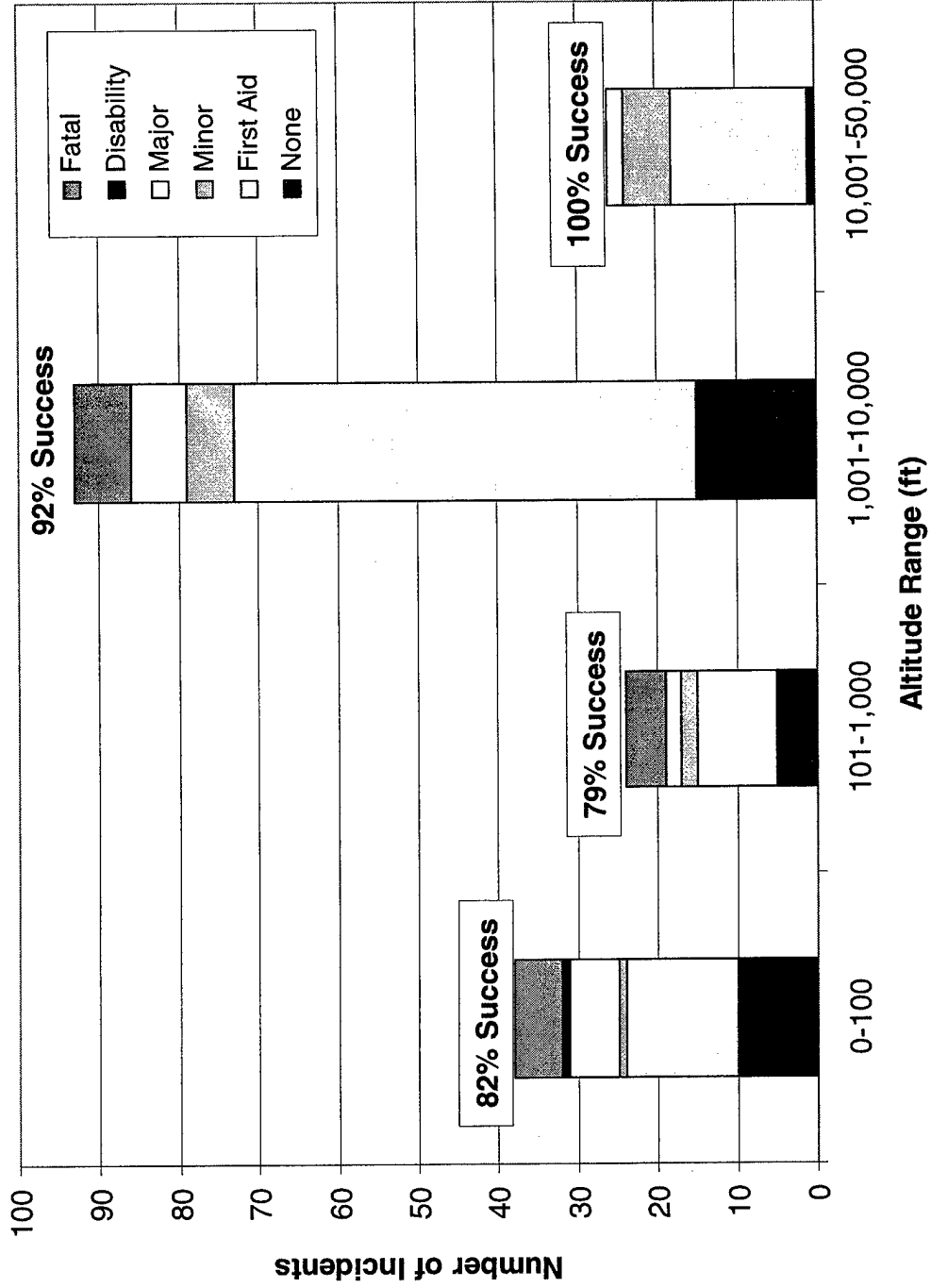
Note: GRU-7 and SJU-17 NACES ejection seats used.

F-14 Crew Ejection Flight Condition/ Injury Category Experience

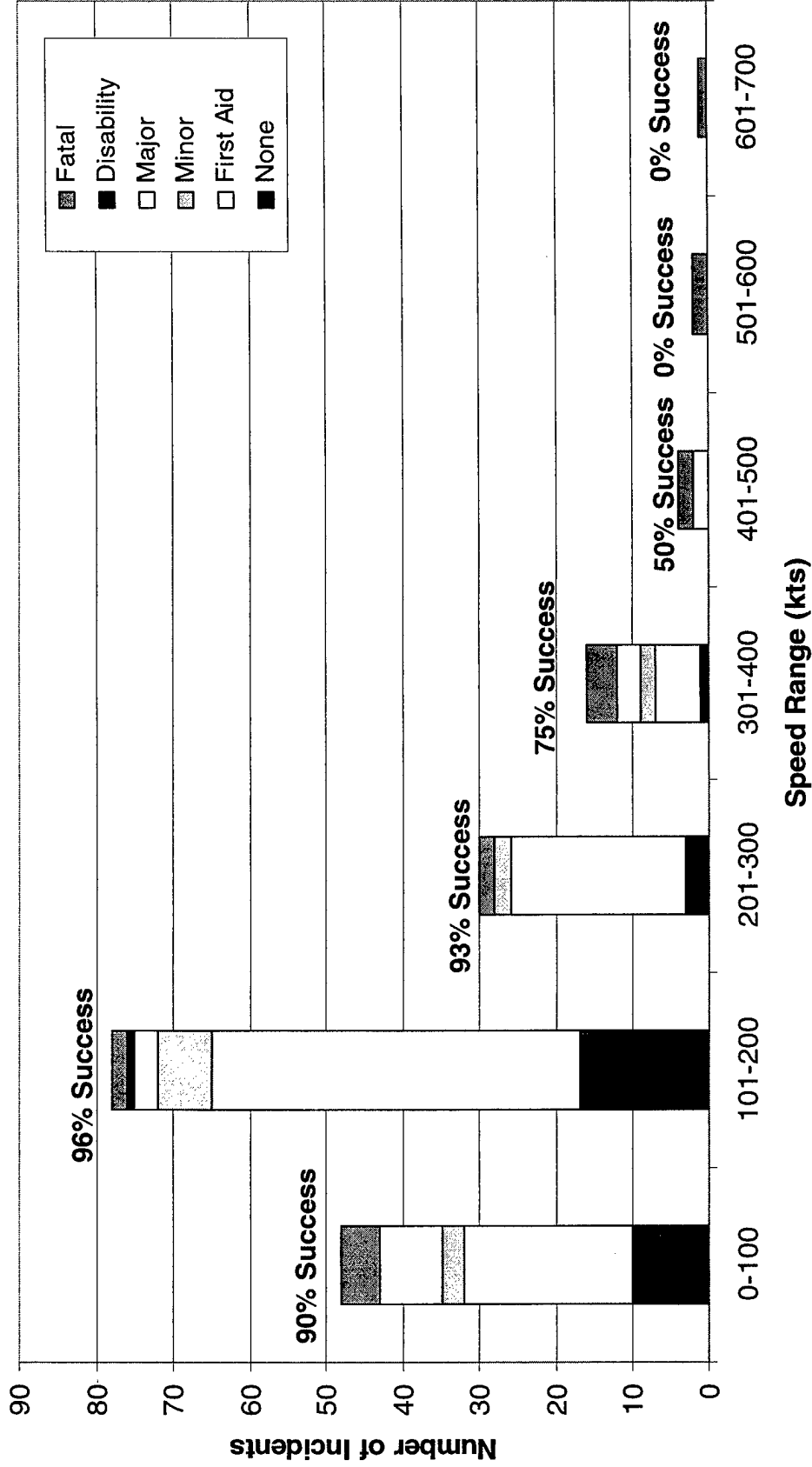


Note: Environment not completely known for 2 ejections

F-14 Crew Ejection Altitude Distribution



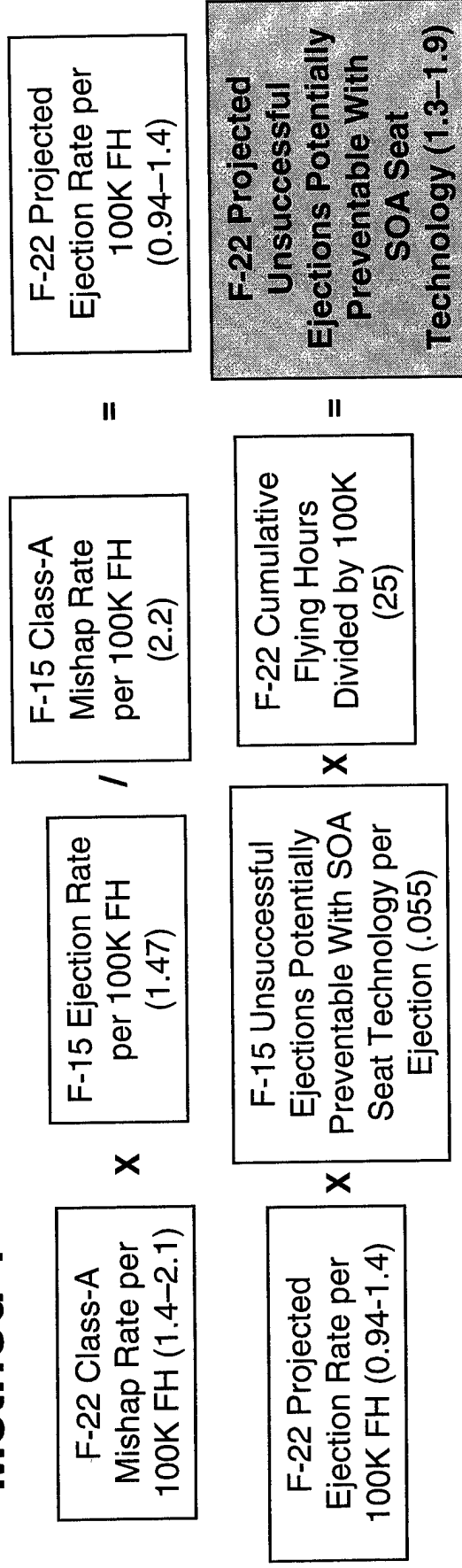
F-14 Crew Ejection Speed Distribution



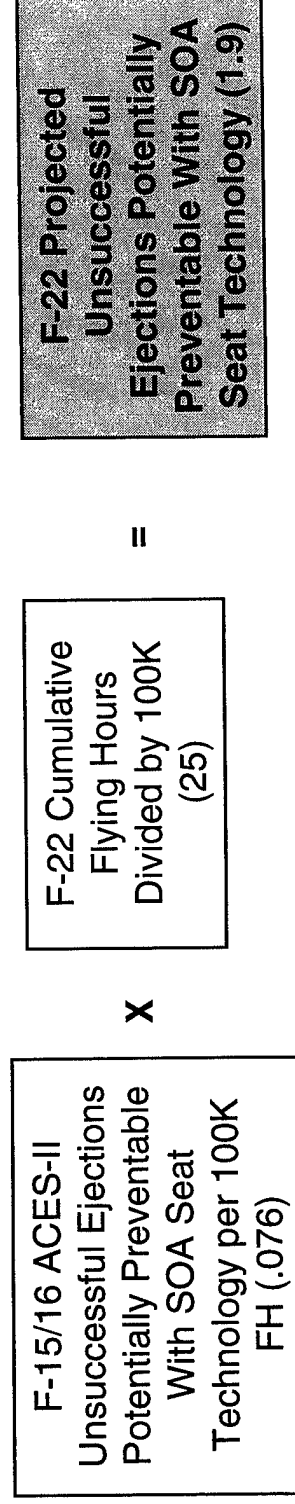
Note: Environment not known for two ejections.

F-22 Aircrew Ejection Predictions

• Method 1



• Method 2



Note: Given uncertainties involved, F-22A pilot ejection fatalities preventable with state-of-art seat technology is less than three (for peacetime training).

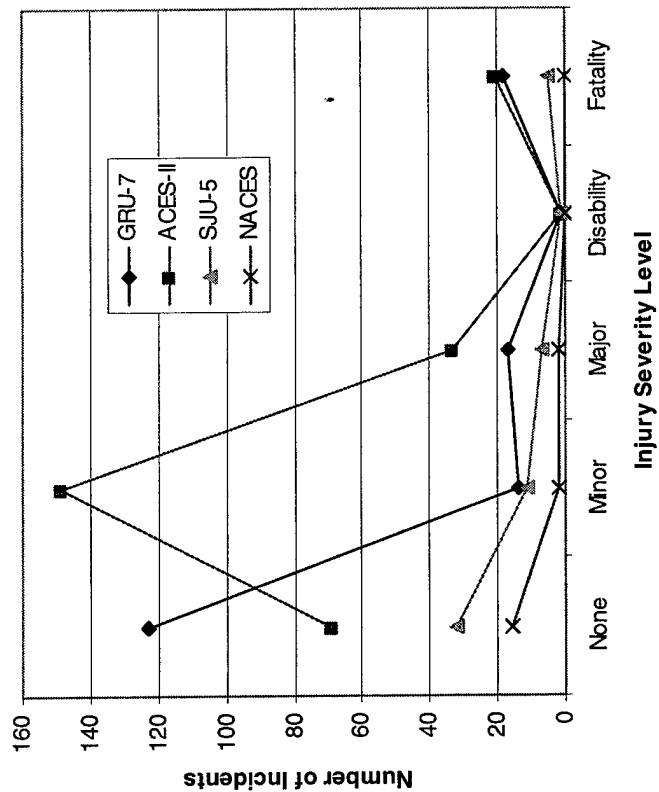
Crew Ejection Seat

Characteristics Summary

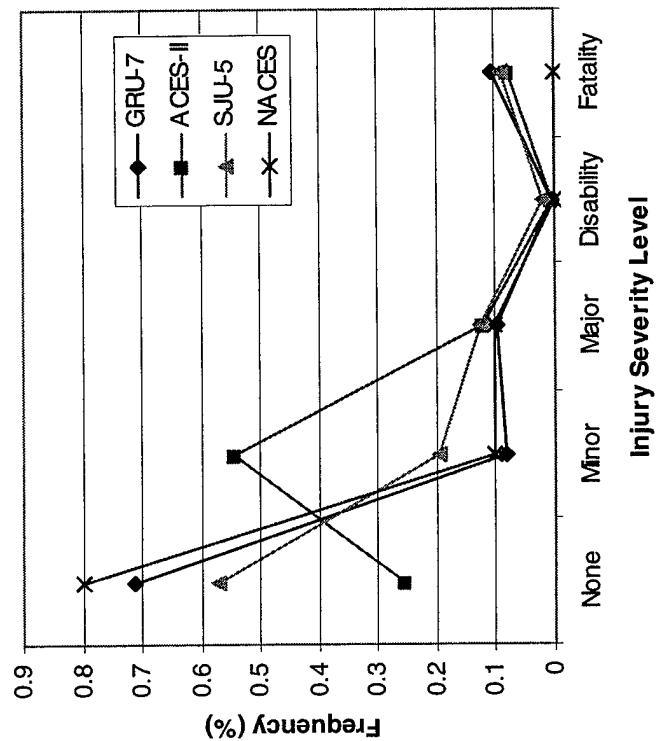
Seat	Status	Crew Weight Range (lb)	Minimum Parachute Deployment Time (sec)	Minimum Parachute Inflation Time (sec)	Flight Parameter Sensing	Ejection Tailoring	High-Speed Stabilization	Drogue Deployment/ Full Inflation Time (sec)	Vertical Descent Rate 300lb (fps)	Steerable /Variable Opening Parachute	Leg Restraint	Arm Restraint	Blast Protection	Weight (lbs)
GRU-7A	Fielded (F-14)	136-215	2.0	3.61	Alt Only	High/Low Alt	Single-Point Drogue	.5/.6-.7	24	Partially/No	Yes	No	No	255
MK-10	Fielded (F-18)	136-215	1.5	2.58	Alt, G	Alt and G	Single-Point Drogue	.5/.6-.7	23	Yes/No	Yes	No	No	250
NACES	Fielded (F-14/F-18)	136-215	0.45	1.87	Alt, Speed, G	Digital 3 Parameter	Three-Point Drogue	.2/.3	21	Yes/No	Yes	No	No	235
NACES P3I	In Qualification	100-245	0.31	1.69	Alt, Speed, G	Digital 3 Parameter	Three-Point Drogue	.2/.3	21	Yes/TBD	Yes	No	No	240
Mk-16	Fielded (Rafale, EFA, Others)	103-245	0.45	1.82	Alt., Speed, G, Weight	Digital 4 Parameter	Four-Point Drogue	.2/.3	21	Yes/Yes	Yes	Yes (integral to suit)	No	180
Mk-16 P3I	In Development	103-245	0.31	1.65	Alt., Speed, G, Weight	Digital 4 Parameter	Four-Point Drogue	.2/.3	21	Yes/Yes	Yes	Yes (integral to suit)	Yes	185 est.
ACES-II	Fielded (F-15, F-16, Others)	140-211	0.20	1.80	Alt, Speed	Alt, Speed (3-mode)	Two-Point Drogue	.17/.4-.5	22.5	Yes/No	No	No	No	170
ACES-II P3I	In Development (For F-22)	103-211 (goal)	0.20	1.80	Alt, Speed	Alt, Speed (3-mode)	Two-Point Drogue	.17/.3-.4	22.5	Yes/No	Yes	Yes (on seat)	No	173
K-36D	Fielded (Mig-29, Su-27, Others)				Aircraft Provided	Roll Attitude, Others	Boom/ Ballute			TBD/No	Yes	Yes (on seat)	Yes	234
K-36D-3.5A	In Development	103-245			Aircraft Provided	Roll Attitude, Others	Boom/ Ballute			TBD/No	Yes	Yes (on seat)	Yes	176

Injury Occurrence and Frequency by Seat Type

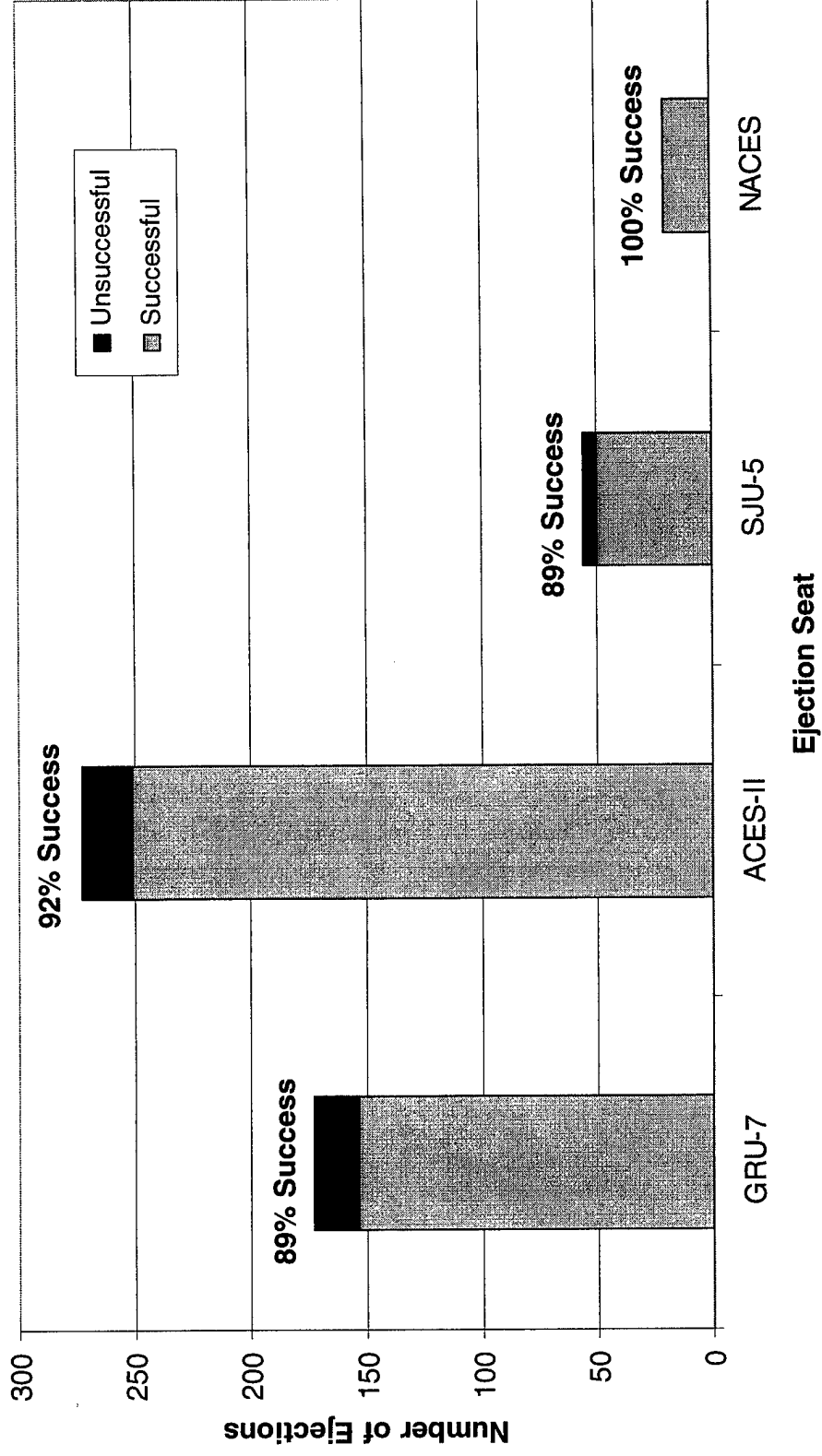
Injury Occurrence by Seat



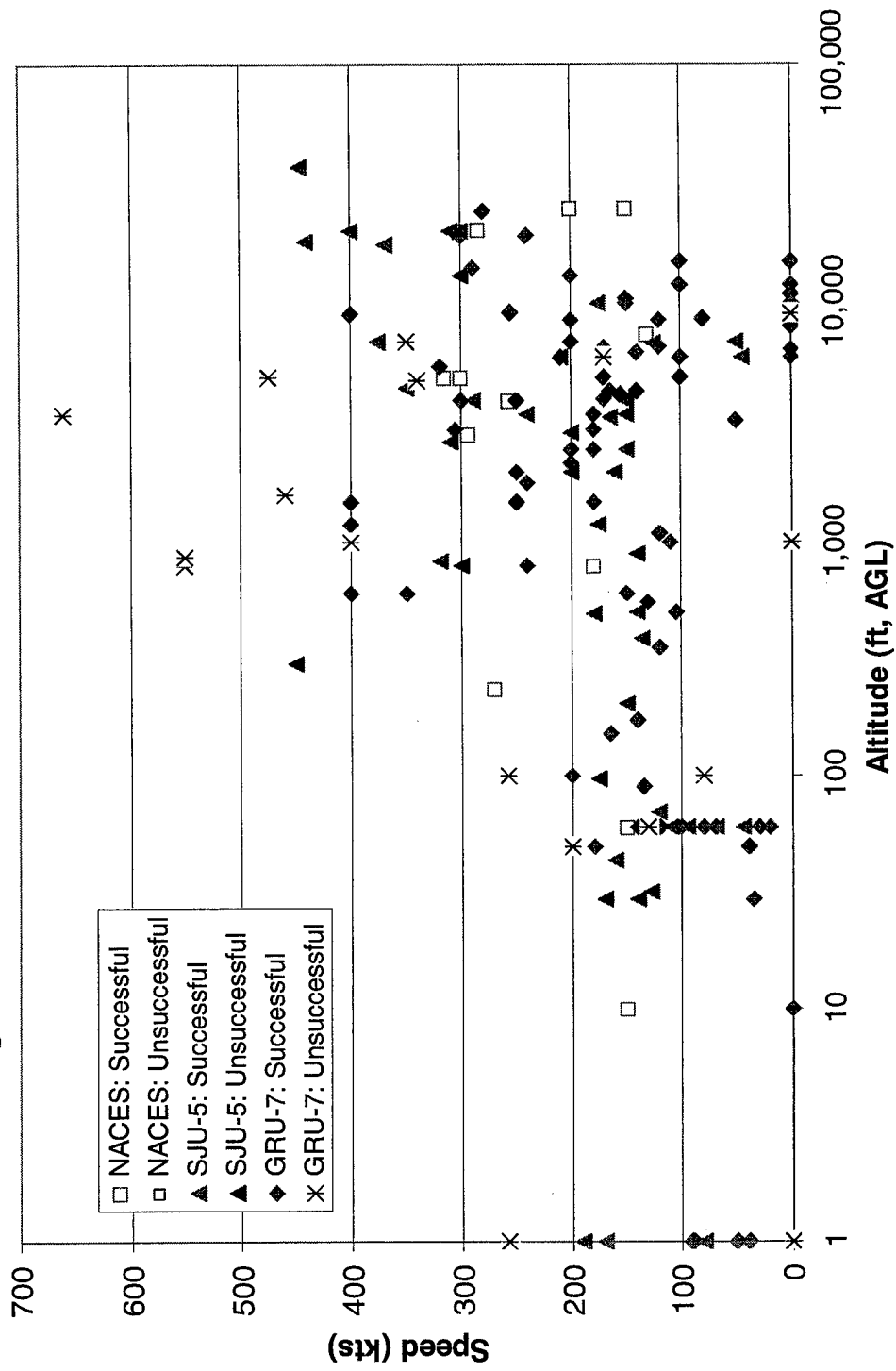
Injury Frequency by Seat



Seat Type Overall Success Rate

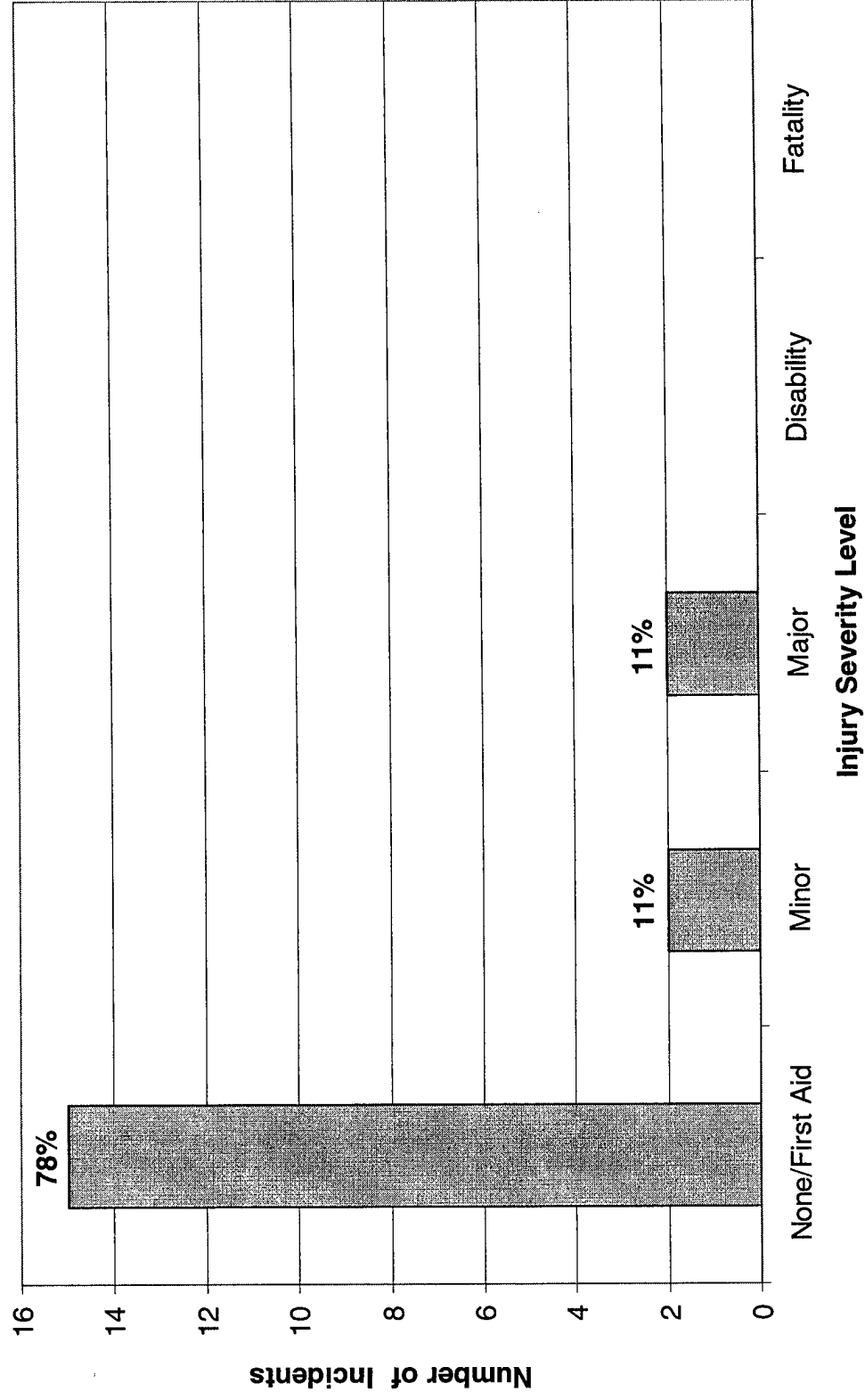


Crew Ejection Flight Condition Experience For Navy Seats



Note: No unsuccessful NACES ejections to date (20 ejections).

USN NACES-Only Crew Ejection Injury Categorization



K-36 Adverse Attitude Performance Estimates

Case Number	Aircraft Attitude (degrees) ^a		Velocity (KEAS)	Altitude Required (ft)		
	Pitch	Roll		MIL-S-9479B	ACES-II	K-36D-3.5A
1	0	60	120	0	0	0
2	0	180	150	200	150	96
3	0 ^b	0	150	300	116	137
4	-60	0	200	500	335	288
5	-30	0	450	500	497	518
6	-60	60	200	550	361	299
7	-45	180	250	600	467	323

Source: USAF ASC/ENFC Flight Systems Engineering Division (based on simulation data).

 = Improved Performance.

^a Conditions at the moment of ejection sequence initiation.

^b At a vertical descent rate of 10,000 ft/min.

Overall Success Rate Ranges for Number of Incidents (Cells with 1 or 2 Incidents per Cell Removed)

Speed (kts)	Altitude (ft, AGL)				
	1-10	11-100	101-1,000	1,001-10,000	10,000-50,000
601-700					
501-600			5	5	
401-500			5	9	
301-400			6	23	9
201-300			9		
101-200		26			
0-100		19	6		

 <75% Success
 75-90% Success
 >90% Success

Speed (kts)	Altitude (ft, AGL)				
	1-10	11-100	101-1,000	1,001-10,000	10,000-50,000
601-700					
501-600					
401-500					
301-400					9
201-300				9	
101-200		26			
0-100	22	19	6		

 <85% Success
 85-95% Success
 >95% Success

APPENDIX B

AIR FORCE REVIEW OF IDA STUDY

After this briefing was given in late May 1999, the Air Force (SAF/AQP) initiated an independent review of it, focusing on the Air Force F-15 and F-16 data. The tasking (with an 11 June letter) was directed to ASC/EN (Lead), 311th HSW/YACL, and the Air Force Safety Center. The review was to examine the validity of the analysis, meaningfulness of the numbers, and conclusions on the bottom line. The results of this review were given to SAF/AQP in a briefing on 27 July.

Overall, the review indicated that the analysis results are comparable. The IDA "lives saved" analysis did not include all ejection factors that the Air Force examined. The Air Force predicted one fewer "save" (6 versus 7) than the IDA study, but this difference was not deemed statistically significant. Another point raised by the Air Force (and included in the IDA study) was that a historical data review does not capture all the issues associated with the current fighter ejection seat situation.

ABBREVIATIONS

ACC	Air Combat Command	JSF	Joint Strike Fighter
ACES	Advanced Concept Ejection Seat	K	thousand
AFB	Air Force Base	KEAS	knots equivalent air speed
AFI	Air Force Instruction	M	million
AFRL	Air Force Research Laboratory	MSL	Mean sea level
AGCAS	automatic ground avoidance system	NACES	Navy Aircrew Common Ejection Seat
AGL	above ground level	O&S	Operations and Support
DoD	Department of Defense	psf	pounds per square foot
EMD	Engineering and Manufacturing Development	SOA	state-of-the-art
F3	form, fit, function	SPO	System Program Office
FCT	Foreign Comparative Testing	USAF	United States Air Force
FH	flying hours	USMC	United States Marine Corps
IDA	Institute for Defense Analyses	USN	United States Navy

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13. ABSTRACT (Maximum 200 words) This annotated briefing looks at the history of aircrew ejection incidents from selected U.S. tactical fighter aircraft with the underlying purpose of determining if using state-of-the-art seat technology (such as that embodied in the Russian K-36D-3.5A design being considered for the F-22A fighter and other U.S. aircraft) could possibly prevent future ejection fatalities. It looks at the current issues surrounding the fighter ejection seat area and the specific seats produced by the three primary manufacturers, the U.S. company Boeing, the British firm Martin-Baker, and the Russian manufacturer Zvezda. The severity of injuries sustained in historical incidents involving U.S. Navy and Air Force aircraft is assessed with regard to the ejection conditions, primarily the aircraft altitude and speed. The authors conclude that, given the conditions expected in the future, an ejection seat that uses state-of-the-art technology could prevent some of the unsuccessful ejection seat incidents projected for the F-22A and reduce the severity of injuries sustained in others.				
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