FLIGHT SAFETY FOUNDATION

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Special Report:

HEAD-UP GUIDANCE SYSTEM TECHNOLOGY – A CLEAR PATH TO INCREASING FLIGHT SAFETY

NOVEMBER 2009

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1. EXECUTIVE SUMMARY

In 1990, Flight Safety Foundation conducted the study *Head-up Guidance System Technology (HGST) — A Powerful Tool for Accident Prevention*. Because almost 20 years has passed since that study, and because the technology and applications have significantly matured during that period, the Foundation felt it beneficial to conduct an updated assessment of the safety benefits of Head-up Guidance System Technology (HGST).

A database was developed for this updated HGST study using the Airclaims Ltd. World Aircraft Accident Summary (WAAS) database, the FSF Approach and Landing Accident database and the FSF Runway Excursion database. The study focused on multi-engine turbojet and turboprop airplanes with MGTW of 12,500 pounds or greater, which generally represent modern glass cockpit aircraft. The resulting HGST study database consisted of 983 commercial air carrier, business and corporate airplane accidents during the time interval from 1995 through 2007.

In both the 1990 study as well as the updated version, Head-up Guidance System Technology (HGST) refers to wide field-of-view Head-up Displays (HUDs) designed to display critical flight information during all phases of flight. Most importantly, HGST provides real-time display of the aircraft flight path vector and acceleration conformal with the real world scene and allows the pilot access to other critical information such as airspeed, altitude, etc. while viewing the outside scene.

The study assumed an operational HGS at the pilot flying station and a properly trained crew. Seventeen distinct safety properties of the HGST were defined. Each of the HGST safety properties was assessed for each accident to determine the likelihood that the respective HGST safety property would have or likely would have prevented the accident. This was accomplished using a subjective evaluation on the part of a highly skilled safety professional. A separate audit was conducted by another safety professional to confirm the analysis standards, and to audit every 10th aircraft accident in the database to assess evaluation consistency.

The study concludes that in modern jet aircraft (glass cockpit) the HGST might have prevented or positively influenced 38% of the accidents overall. Of those accidents where the pilot was directly involved, such as takeoff and landing and loss-of-control accidents, the likelihood of accident prevention due to HGST safety properties becomes much greater, 69% and 57%, respectively.

2. INTRODUCTION

In 1990, Flight Safety Foundation undertook a study of the benefits of Head-up Guidance technology to aviation safety. That study was completed in late 1990 and the results were published by the Foundation in the September 1991 *Flight Safety Digest*.

That study assessed what might have been the likely outcome of the reviewed accidents if properly operating head-up guidance equipment, correctly operated by a crew trained to use such equipment, had been in use aboard each accident aircraft. The study focus was civil jet transport accidents during the period between 1959 and 1989. In that study, the Foundation concluded that civil jet transport aircraft equipped with properly functioning head-up guidance system technology would have experienced significantly fewer accidents and reduced loss of life.

Twenty years have elapsed between the end of that study period and the present. During these two decades, the fleet of commercial transports has changed significantly. First and second generation large commercial jet transports have generally been replaced by airplanes with glass cockpits and avionics systems based on digital technology. Corporate airplanes have also undergone the change to digital avionics and electronic flight displays. Smaller regional jet and turboprop airplanes, many incorporating electronic displays and digital technology, have taken over much of the regional feeder operation. The substantially increased capabilities of modern avionics systems have increased the potential for improved safety through accident prevention.

In 1996, the Foundation created the Approach and Landing Accident Reduction (ALAR) task force as follow-on to its research activities in that area and in Controlled-Flight-Into-Terrain (CFIT) accidents. Since then, the Foundation's efforts to reduce accidents have been extremely well received by the aviation community. Underlying these activities were several research studies that were initiated in the early 1990s and largely concluded by 1998. The results were compiled and published in Volume 17, No. 11–12, and Volume 18, No. 1–2 of the FSF *Flight Safety Digest,* published as a combined issue for November 1998 through February 1999. The issue was entitled, "Killers in Aviation: FSF Task Force Presents Facts about Approach-and-landing and Controlled-flight-into-terrain Accidents."

A large number of aviation organizations and individuals was involved in conducting those studies and compiling the needed resources. Flight Safety Foundation's outreach to the aviation community on ALAR and CFIT culminated with numerous additional publications and guidelines optimized for easy use by flight crews and aviation management personnel.

At the time those studies were conducted, the research teams used the most current databases available which contained data on accidents which would yield information on the use of HGST and the reduction of both CFIT and ALAR accidents. Because the results of those studies were based on data that were considered to be beyond useful life, the Flight Safety Foundation opted to update the

databases for CFIT and ALAR, understanding that the resultant interventions were still valid. The Foundation also determined that a need existed to update and review the capabilities of currently available HGST when mapped against accidents that occurred over the period 1995 to 2007.

Against that backdrop, the Foundation took the decision to study the potential of current generation head-up guidance systems for accident risk reduction and prevention as applied to the current generation of civil jet and turboprop transport airplanes and modern corporate and business airplanes. This HGS study addresses a considerably broader fleet than that of the initial study, which was limited to large jet transports.

3. Methodology

HGST has incorporated major technological advances to improve safety over the last 20 years since the original FSF study was conducted. Many of those advances are portrayed in the HGS safety properties listed in paragraph 3.b.

The study was designed to map each accident that occurred in the selected population against each of the safety properties listed in paragraph 3.b. This was accomplished using a subjective evaluation on the part of a highly trained safety professional. Following that assessment an audit was conducted by a separate safety professional. The audit was conducted on the first 20 accidents to compare a body of work against the initial audit as a means of confirmation that both the analysis and the audit were conducted using the same standards. Following this process, and as a quality control mechanism, a random audit was conducted on the initial assessment covering every 10th aircraft accident in the database.

3.a. General Approach

The study airplane fleet consisted of both Western- and Eastern-built airplanes that, with minor exceptions, have entered service beginning in 1980 and later. This generally addresses airplanes that have incorporated some level of digital technology in avionics and flight systems, and would be considered to be, by today's standards, "modern" airplanes. The subject fleet included multi-engine turbojet and turboprop airplanes with a MGTW of 12,500 pounds and greater. Military and special use airplanes were excluded from the study.

The study addressed worldwide accidents during the 13-year period from the beginning of 1995 through 2007. The accident/incident database for this HGS study utilized the World Aircraft Accident Summary (WAAS) Ascend Division of Airclaims Ltd. database, the FSF ALAR database and the Runway Safety Initiative (RSI) Runway Excursion database. Where possible, the WAAS database was supplemented with the more detailed accident records from Ascend's Major Loss Records (MLR) database, the accident database of the National Transportation Safety Board (NTSB), and accident data resources from other countries, as appropriate. The goal was to gather enough relevant information about each accident/incident to ensure the HGST assessment was as accurate as possible.

However, in some cases the data were inadequate to make a reasonable assessment of the accident situation. In these cases, the assessment was marked as “Unknown.”

The selection process is shown in Appendix C and resulted in 983 accidents which met the study criteria and time interval. A list of airplanes that met all the inclusion criteria that have had accidents during the 1995 through 2007 time period is included as Appendix A. The specific aircraft that were involved in accidents during that time period, but were excluded from the study, are listed in Appendix B.

Accidents in the database that were clearly ground accidents were also deleted from the study. The criterion for exclusion was that the accident happened on the ramp or immediately adjacent taxiways. Many of these accidents involved loading or servicing the aircraft. This definition of ground accident is consistent with the previous FSF Ground Accident Prevention (GAP) Program. Accidents that occurred on the active runway or active taxiway remained in the database.

The focus of the study was to determine the percentage of the accidents that would or might have been prevented by the application of the HGST safety properties. The study process began by developing a thorough understanding of the HGST properties that are relevant to accident prevention. The HGST safety properties in paragraph 3.b. were used to determine the accident prevention properties that could have been employed to reduce or eliminate the chance of the accident’s occurrence. Each relevant accident was analyzed from the perspective of HGS prevention and intervention potential. The analysis subjectively assessed how the use of HGST and the HGS accident prevention/intervention property or properties might have interrupted the chain of events leading to an accident or incident.

For the purposes of this study it was assumed that the pilot flying the accident aircraft was properly trained and had an operational HGST. The HGS accident assessment assigned accidents to one of the following five categories, which are similar to those of the previous FSF HGS Study:

Yes	It is **highly likely** that HGST might have prevented the accident/incident.
Yes (?)	It is **likely** that the HGST might have prevented the accident/incident.
No (?)	It is **unlikely** that HGST might have prevented the accident/incident, but information is inadequate to determine with further certainty.
No	It is **highly unlikely** that HGST might have prevented the accident.
Unknown	Insufficient information is available to reach a reasonable conclusion about the influence HGST might have had in the accident.

3.b. HGS SAFETY PROPERTIES

The following safety properties of the HGST were reviewed in connection with each aircraft accident. The goal was to determine whether or not the individual safety property would have had any effect on the outcome of the accident sequence.

3.b.1. Flight Path Vector

The Flight Path Vector is inertially derived and provides instantaneous indication of where the aircraft is going relative to the outside world on a conformal display.

3.b.2. Flight Path Acceleration

The acceleration (or deceleration) of the aircraft along the flight path is indicated by the Flight Path Acceleration symbol. The flight path acceleration is made up of the total acceleration forces acting on the aircraft, including acceleration generated by both the aircraft in the form of thrust and acceleration generated by the air mass the aircraft is moving through. To avoid confusion in the control of aircraft thrust, the Flight Path Acceleration symbol is removed from the display when the HGS detects a low-level decreasing performance windshear.

3.b.3. Guidance Cue

The guidance cue provides lateral /vertical guidance from the Flight Control Computers (FCC) and provides lateral/vertical guidance to touchdown through rollout from the HGS computer. It also provides takeoff guidance from the HGST computer for lower-than-standard takeoff minimums.

3.b.4. Speed Error Tape

The speed error tape provides a positive or a negative presentation of airspeed difference between actual and selected airspeed with an intuitive tape presentation. It also provides the pilot very precise control of speed in conjunction with the inertia caret.

3.b.5. Runway Remaining

The Runway Remaining symbology provides a digital readout in 500 foot increments during the takeoff ground roll and Category III Mode Rollout. The symbol simulates the runway markings such that the display will show a decrement by 500 feet as each marker is passed.

3.b.6. Deceleration Rate Index

The deceleration rate index presented using the inertia caret indicates deceleration with respect to the airplane autobrake algorithms or other deceleration references familiar to the crew. The inertia caret algorithms run independently in the HGS computer and present an inertially derived deceleration indexed on the combiner. The index on the combiner is presented

with indices that represent set values that correlate to the airplane autobrake settings or to other deceleration performance references useful to the crew.

3.b.7. Unusual Attitude Display

During unusual attitudes, the HGS display automatically switches to a format designed for recognition of and recovery from the conditions. When the airplane attitude is restored to a stable condition, the display format is returned to the selected operating mode.

The HGS Unusual Attitude mode main display feature is a large attitude sphere in the center of the display with a distinct sky/ground indication. The basic airspeed and altitude scales from the Primary mode are also displayed, and the rest of the display is de-cluttered for concentration on the basic flight information. The Unusual Attitude mode is automatically entered and exited, overriding the currently selected normal operational mode on the display.

3.b.8. Autonomous Flare Guidance

The Flight Path Canards will appear attached to the sides of the Flight Path. They appear at approximately 105 feet altitude AGL. They serve as reference points that position them in line with the Autonomous Flare Cue when the flare maneuver is being correctly executed.

The Autonomous Flare Cue provides flare symbology in PRI, IMC and VMC modes. The symbol is both a flare anticipation and flare symbology cue. To distinguish between these two functions the dashed lines will become solid lines when the symbol is to be used as a flare symbology cue.

The No Flare Annunciation provides an indication that Autonomous Flare symbology cannot be provided. The symbol is displayed in the upper left area of the display.

3.b.9. Tailstrike Limit and Tailstrike Advisory

On takeoff the HGS provides a Tailstrike Limit symbol that is displayed when the pitch attitude indicates that the airplane is rotating at a rate or to and extent that will cause a tailstrike. The symbol looks like a bar bell: O----O. In order to avoid a tail strike, the pilot must not allow the boresight symbol to pass through the Tailstrike Limit symbol.

On landing, a Tailstrike Advisory is displayed in text on the combiner when the airplane is in an attitude or flares at a rate that would cause the airplane to strike the tail. This is caused by improper configuration, significant negative speed deviation or pilot induced oscillation from over-rotating during the flare.

3.b.10. TCAS Guidance

When a Resolution Advisory (RA) is received from the TCAS Computer, a TCAS Resolution Advisory Symbol is displayed on the HGS display. TCAS Resolution Advisories are either corrective or preventive. Corrective advisories are issued when the aircraft vertical flight path must be altered to avoid a collision, while preventive advisories are issued when an intruder is within range, but the current vertical flight path of the aircraft is safe and the pilot only needs to monitor vertical speed.

When a Corrective Up or Corrective Down TCAS Resolution Advisory is received by the HGS, the Corrective Resolution Advisory symbol is displayed indicating the “fly to” region for the Flight Path symbol to avoid a collision with the other traffic.

When a Preventive Up or Preventive Down TCAS RA is received by the HGS, the Preventive Resolution Advisory symbol is displayed indicating the safe region for the Flight Path symbol to avoid interference with other traffic.

3.b.11. Windshear Avoidance/Recovery Guidance/Performance Margin Awareness

Early recognition of wind shear is identified by observing the erratic wind direction and wind velocity on the wind direction symbol and velocity symbol. The HGS /HUD will provide an intuitive and immediate identification of performance margin available to the pilot during a windshear recovery by displaying the AoA limit symbol. The pilot maintains the flight path vector over the solid guidance cue and between the zero degree pitch line and the AoA limit symbol. The pilot is able to monitor the energy of the airplane via the inertia caret, which combined with the Speed Error Tape, can also provide indications of windshear conditions. To avoid confusion in the control of aircraft thrust, the Flight Path Acceleration symbol is removed from the display when the HGS detects a low-level decreasing performance windshear.

3.b.12. Improved Pilot Performance during Engine Failure on Takeoff Operations

The following symbols provide the pilot with a more intuitive method to quickly ascertain airplane state, stability, performance and performance margin.

Flight path vector

Inertia caret

Speed error tape

Slip skid

Zero degree pitch line

Angle of Attack Limit (AoA)

This set of symbols allows the pilot to quickly and intuitively determine the inputs required to stabilize the airplane for engine-inoperative flight. The flight path displays the airplane's path referenced to the zero degree pitch line to establish a positive rate of climb. The AoA limit symbol provides the pilot a visual reference establishing the maximum ascent capability. The area displayed between the glideslope reference line and the AoA limit determines the performance margin available. The flight path also presents lateral position and when referenced to the slip/skid indicator intuitively provides guidance to the pilot to apply the appropriate rudder forces to stabilize the airplane laterally. The speed error tape presents precise speed control to maintain the designated speed for the engine-out condition. Since the speed the pilot must maintain can vary with when the engine failure occurred during the profile, the speed error tape can be a significant benefit to the pilot in establishing and maintaining the desired speed.

3.b.13. Surface Movement Guidance

Surface Movement Guidance is a system that will help pilots navigate better on airport taxiways and runways. This Surface Guidance System (SGS) uses an airport database to identify the centerline and edges of the current runway or taxiway the aircraft is operating on, and display virtual centerline, edge lines, signs and other symbols that overlay the actual airport taxiways, runways and signage on a conformal Head-Up Display. With this extra situational awareness, pilots will be able to maneuver on the ground with confidence and minimize runway incursions. This capability will utilize multiple technologies to provide accurate position information to ATC and other aircraft.

3.b.14. Weather Avoidance

The zero degree pitch line can be used to determine whether the airplane has the ability to safely fly over low-level thunderstorms in the airplane's path, or the flight path vector can be used to determine a safe and efficient route to circumnavigate thunderstorms.

3.b.15. Selectable Descent Path — Glideslope Reference Line

The reference setting for glideslope is indicated by the position of the Glideslope Reference Line relative to the Horizon Line. The Reference Glideslope value is also displayed digitally at both ends of the Glideslope Reference Line. The Glideslope Reference Line is a conformal display representing the glideslope value selected on the HCP or MCDU or received from the FMC, meaning that the Glideslope Reference Line overlaying a point on the ground indicates that the airplane position is at an angle equal to the glideslope reference point. Maneuvering the aircraft so that the Flight Path symbol overlies any point along the symbol's dashed line results in a descent angle equal to the glideslope value selected. Initiating a descent when the Glideslope Reference Line overlays the runway touchdown zone allows a constant descent angle approach to be flown with purely visual information.

3.b.16. Energy Management during RTO

The inertia caret and deceleration index are used to monitor the Rejected Takeoff (RTO) function. The inertia caret and deceleration index presentation display to the pilot the stopping efficiency and capability of the airplane. The pilot knows the stopping value associated with indexed points of the display and the inertia caret presents the level of braking effect the system is experiencing.

3.b.17. Angle of Attack (AOA)

The Angle of Attack Scale and Indicator is displayed in the upper right of the display. It consists of a round dial with pointer and a digital readout that indicate the aircraft's current angle of attack.

The angle of attack approach reference band is displayed on the Angle of Attack Scale. It indicates the normal approach angles of attack when the flaps are in a landing position.

The angle of attack stick shaker trip point is displayed to provide a visual indication of the aircraft's stick shaker angle of attack.

4. Aircraft

This study focused on modern multi-engine turbojet and turboprop aircraft with glass cockpit technology which entered service in 1980 or later and which are 12,500 pounds MTGW or greater. For purposes of this study military aircraft, special use aircraft (e.g., CL 215/214), and helicopters have been excluded. The list of aircraft addressed in the study is presented in Appendix A. The list of aircraft that had accidents but were not included is attached as Appendix B.

5. Analysis and Results

The following sections present the results of the analysis, first for the entire database of accidents, then for each of the major categories of the WAAS database as defined by the initiating event of the accident. These categories are presented in the order of greatest HGST influence.

5.1 Data Assessment for Overall Database

The final assessment database consisted of 983 accidents.

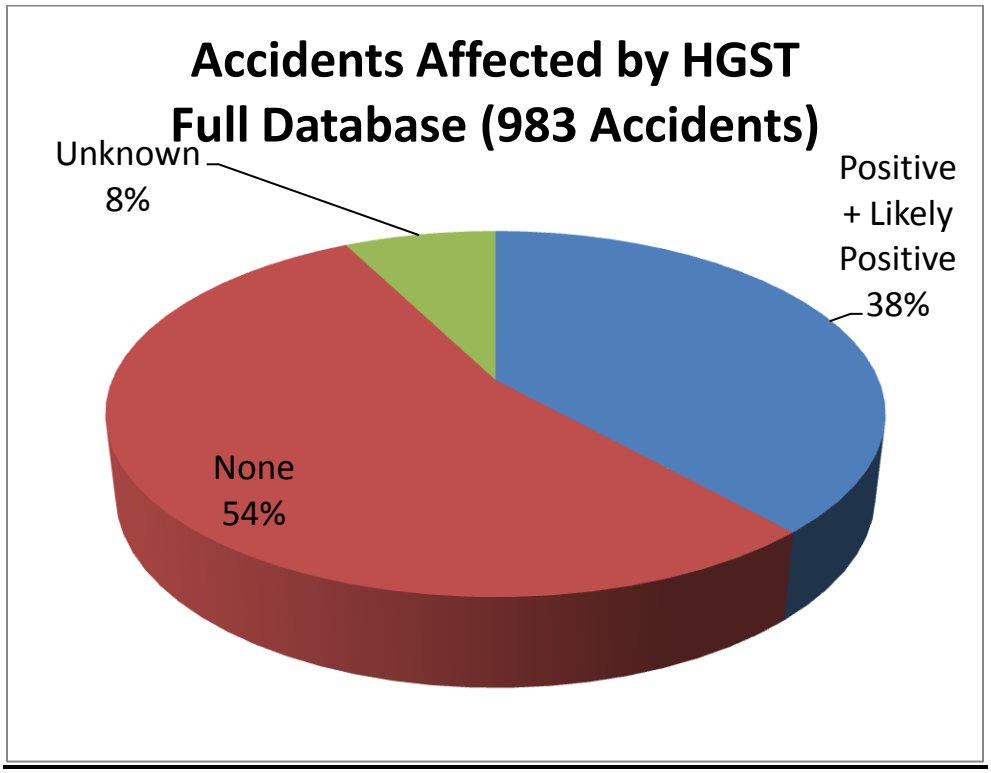


Figure 1 Overall Study HGST Affects for Accident Prevention

As shown in Figure 1, of the 983 accidents, 38% would have been influenced positively by the use of HGST. Some 54% would not have been influenced by the technology, and 8% did not have adequate data to make an assessment.

The specific safety properties that were judged to be relevant are shown in the following figure.

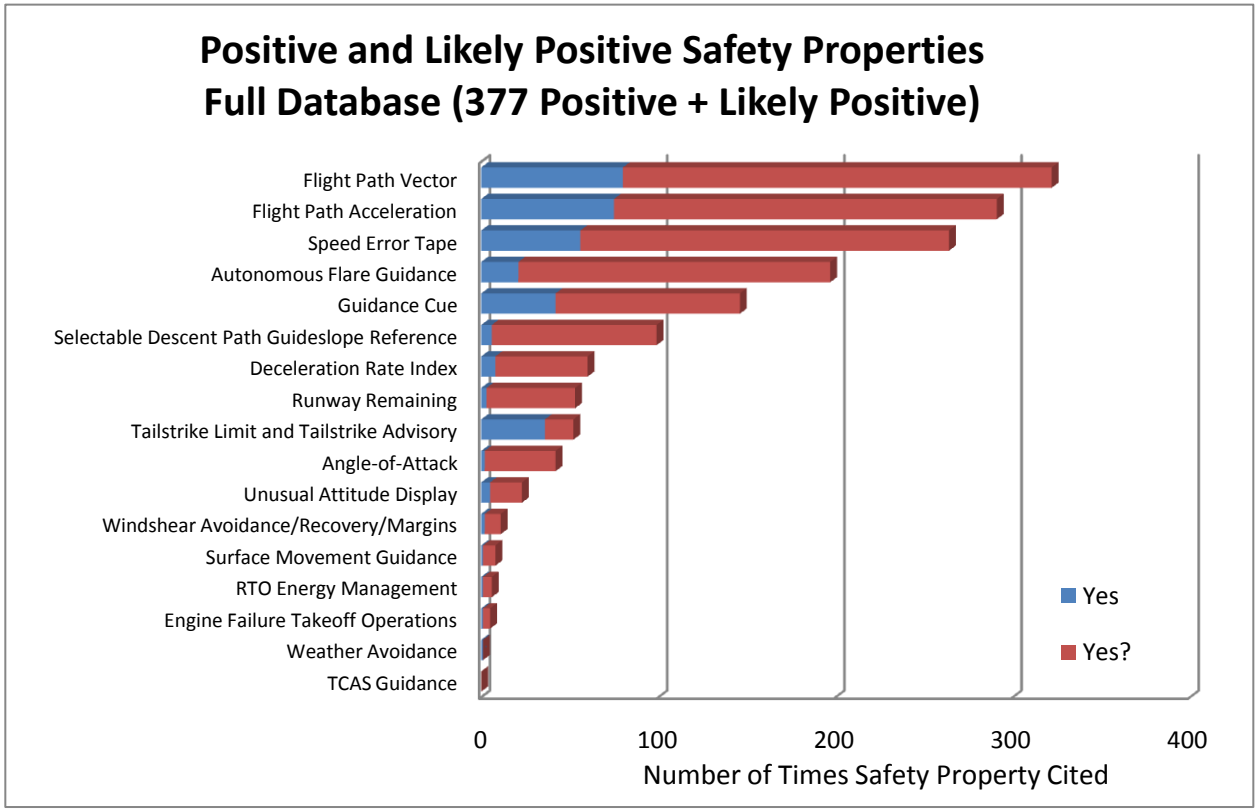


Figure 2 Ranking of Safety Properties for Full Database

The frequency of involvement of specific safety properties are ranked in Figure 2. Generally, if the HGST had a positive effect on the accident, there was often more than one relevant safety property. For example, in takeoff or landing accidents, control of the airplane state would have been enhanced by a combination of Flight Path Vector, Flight Path Acceleration, and Speed Error Tape.

Those accidents where pilot involvement was critical were the accidents most likely to be positively influenced by the use of HGST. Several categories of accidents had little to do with the flight crew involvement, and consequently would not have been affected significantly by HGST.

Figure 3 shows the distribution of the Positive and Likely Positive assessments across the range of database accident categories. The categories most affected by HGST are Takeoff and Landing and Loss of Control. Conversely, categories such as Explosion and Fire, Mechanical Failure, and Environment are unlikely to be affected by HGST. Each of these categories will be reviewed in the following sections.

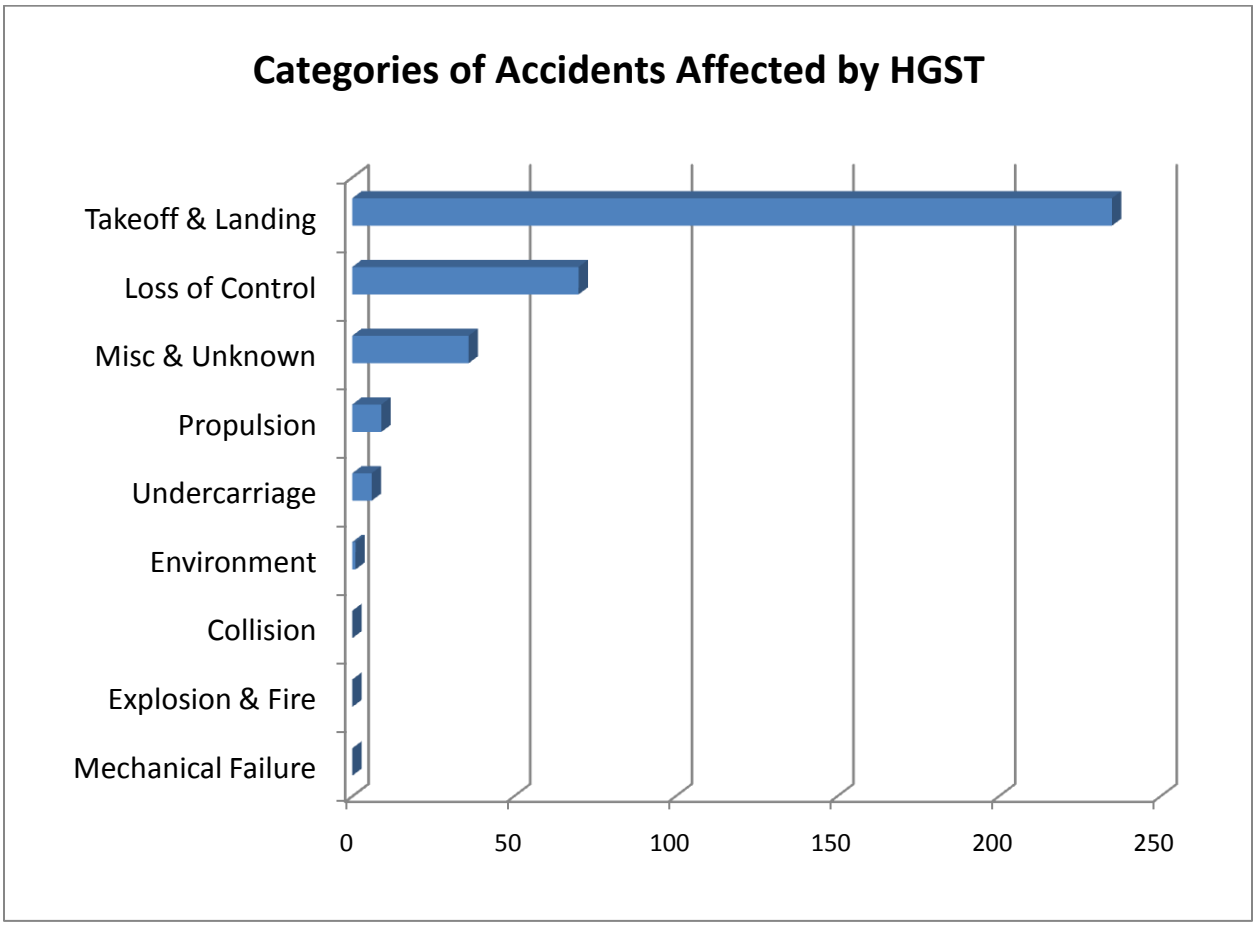


Figure 3 Categories of Accidents Positively Affected by HGST

5.2 Takeoff and Landing Accidents

The largest category of accidents in the database was the Takeoff and Landing category. It consisted of 341 of the 983 accidents, more than a third of the accidents. Within that category, in more than two thirds of the accidents, HGST would have positively or likely positively influenced the outcome, as shown in Figure 4. In only a quarter of the accidents was the HGST unlikely to have positively influenced the outcome. Although this category includes both takeoff and landing, the landing accidents typically outnumber the takeoff accidents by a factor of four, i.e., approximately 80% of the accidents in this category are associated with landing.

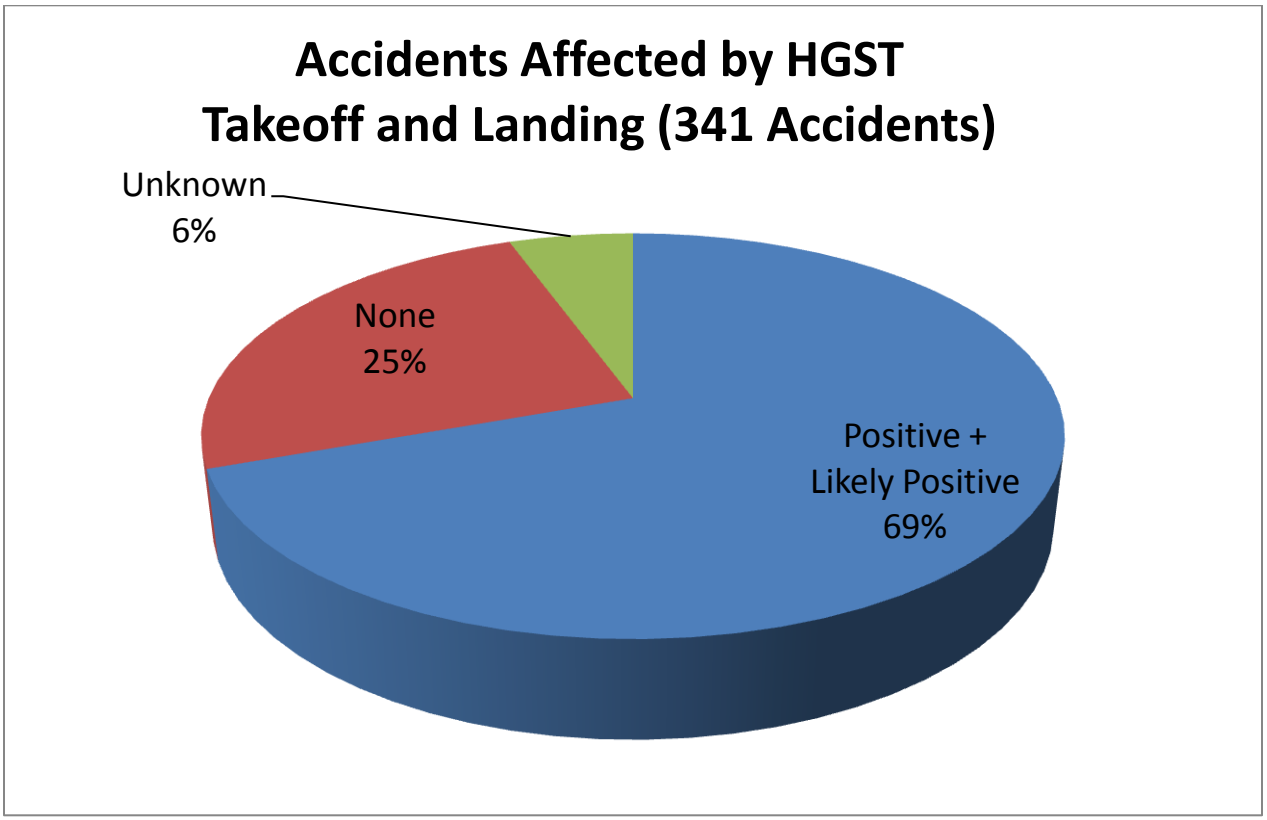


Figure 4 HGST Influence in Takeoff and Landing Accidents

The involvement of the specific HGST safety properties is shown in Figure 5.

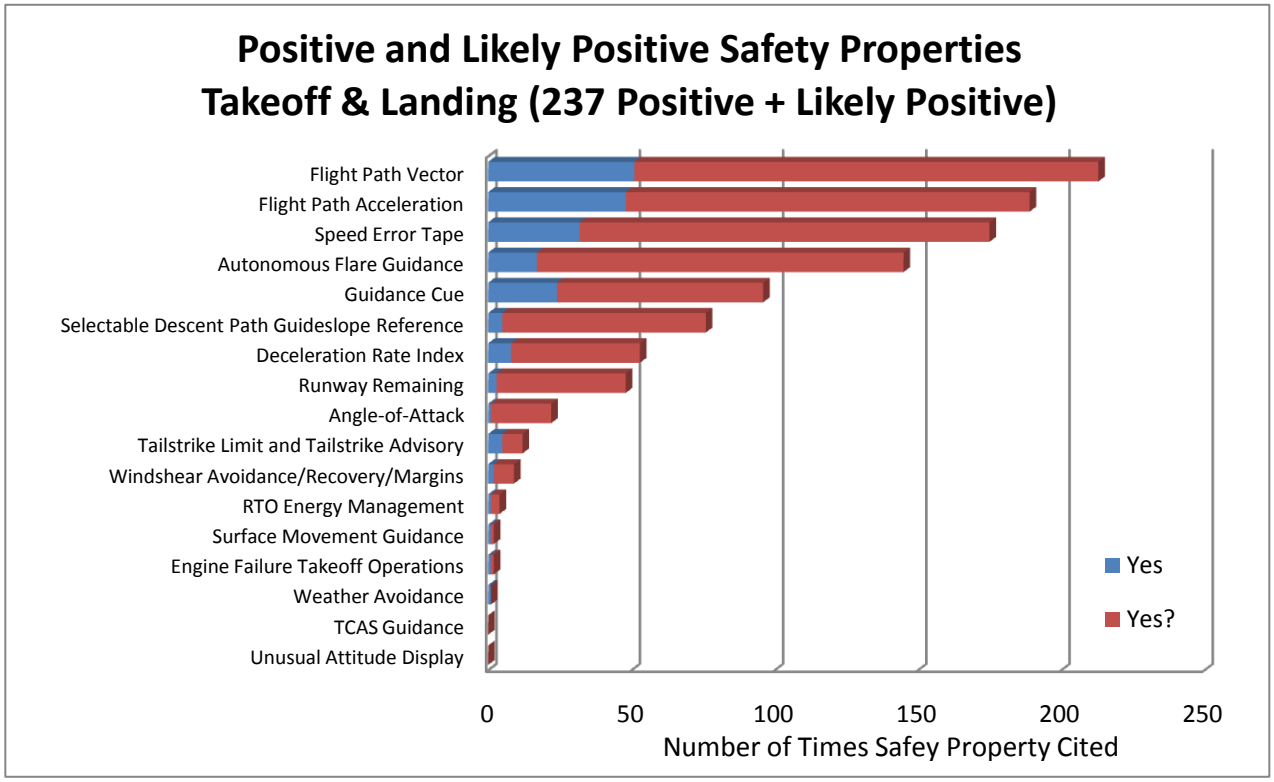


Figure 5 Ranking of Safety Property Influence for Takeoff and Landing Accidents

The most important information on the display consistently appears to be flight path and speed error information, and would have positively influenced the majority of these accidents. Flare guidance information would have positively influenced almost half of the accidents in this category. Since approximately 4 out of 5 accidents in this category are landing accidents, the influence of flare guidance is even more significant, since this guidance applies only to landings. Where guidance information was available, the display of those data on the HGS was very significant. In many of the accidents, a precision approach was not flown. In those cases, the Selectable Descent Path Glideslope symbology presented the means to increase the precision of a non-precision approach.

An example of the type of accident in this category is described in the following narrative taken from the Database:

> "Following an ILS approach to Runway 06L at Cleveland, the aircraft landed long and fast and was then not stopped before the end of the runway. It overran, through the ILS localizer antenna, and eventually came to rest about 600ft. beyond the end of the runway. During the overrun the aircraft's nose undercarriage failed and collapsed rearwards.The accident happened in daylight (1248L) but in IMC. Wind 340deg./22kt., gusting to 35kt., visibility 0.5sm in snow, runway RVR

4,000ft., broken cloud at 1,100ft. and overcast at 1,600ft., temp -3F and dew point -4F. At 1147L a NOTAM was issued which described Runway 06L/24R as being covered with thin wet snow. The runway had been 'broomed' for its full length and liquid de-icer and sand applied. 'Tapley' braking action readings at that time for touchdown, middle and rollout zones were given as '60', '60' and '60' - 'Good.' After the accident new 'Tapley' readings varied between '25' and '30' - 'Medium to Poor', for all sections of the runway. Runway 06L at Cleveland is 6,800ft. long but the landing threshold is displaced by 530ft. The runway has an asphalt surface.The aircraft was operating a flight (2051) from Windsor Locks."

5.3 Loss-of-Control Accidents

The next major category where HGST would have been influential is the category of Loss-of-Control accidents. This category represented 123 of the 983 accidents evaluated. Of particular importance is that the HGST would have positively or likely positively affected more than half of the accidents in this category, as shown in Figure 6.

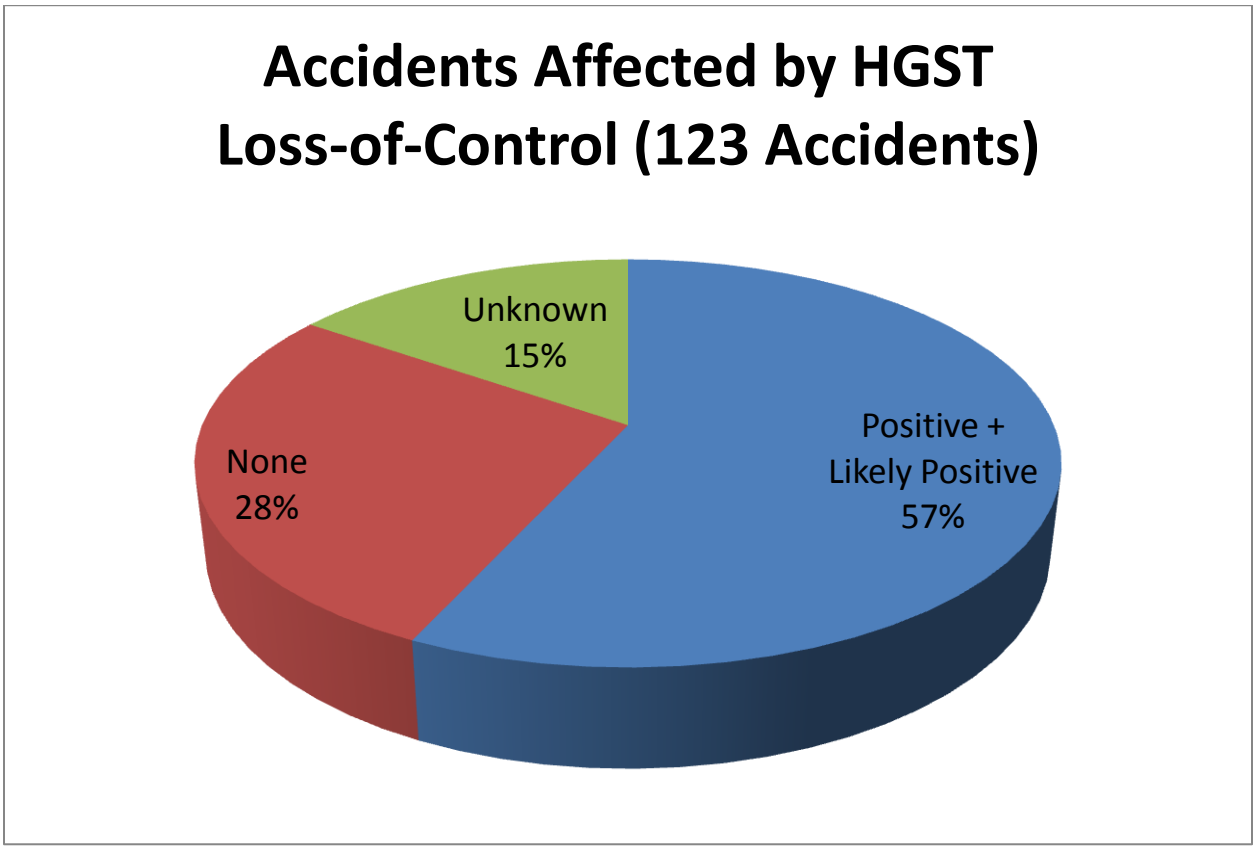


Figure 6 HGST Influence on Loss-of-Control Accidents

The distribution of HGST safety properties is shown in Figure 7. The top safety properties are again the same three factors; Flight Path Vector, Flight Path Acceleration, and the Speed Error Tape. All three of these represent some aspect of the energy of the airplane.

The instance of tail strikes in Loss-of-Control accidents is relatively high and the value of the display of tail strike limit angles and advisories becomes significantly greater. In many cases, the Unusual Attitude symbology would have come into play as well.

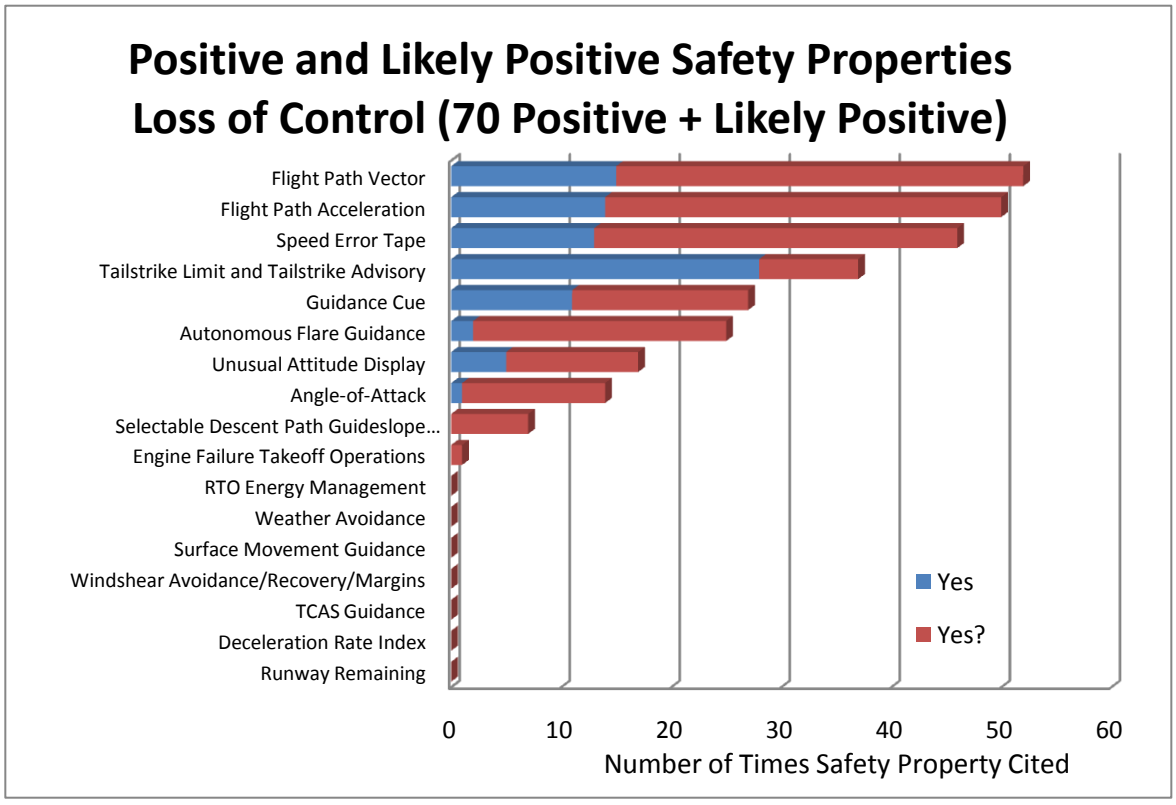


Figure 7 Ranking of Safety Property Influence for Loss-of-Control Accidents

An example of the typical accident in this category is described in the narrative as follows:

> "Following an apparently normal take-off and initial climb from Runway 15 at Lima, about 3min. after departure, the co-pilot advised ATC that they had problems and wanted permission to return to Lima for an immediate landing. The co-pilot apparently told ATC that they had altitude and airspeed discrepancies. The airspeed was 'too low' and the aircraft's altitude was 'increasing too slowly'. Additionally, the wind shear warning had sounded for no apparent reason. ATC began to provide radar vectors to position the aircraft for a landing on Runway 15. Sometime later, when the aircraft was roughly on the base leg of the approach, control seems to have been lost and the aircraft crashed into the sea off Ancon, to the North of Lima. At impact, the captain's flight instruments were apparently indicating an airspeed of about 450kt. and an altitude of 9,500ft. The

aircraft crashed 29min. after take-off. According to press reports, one of the last transmissions from the flight was that 'the computers have gone crazy'. The accident happened in darkness (0111L). Weather; wind, light/southerly, 900ft. overcast and visibility 3km. The aircraft was operating a continuation of the PL603 service to Santiago. The flight originates at New York and has stops at Miami and Quito. There is an aircraft change at Lima. Subsequently press reports have quoted the Peruvian Transport Ministry as saying that three of the aircraft's static ports on the left side of the fuselage were found covered (blocked) by adhesive tape. The tape, which is said to be a neutral colour, was reportedly applied by Aeroperu maintenance personnel at Lima to protect the ports during washing and polishing prior to the accident flight. It is understood that the cause of the accident has been attributed to 'computer problems as a result of adhesive tape covering the aircraft's static ports."

5.4 Miscellaneous Accidents

This category of accidents represents a mixture. The WAAS database developers did not consider these accidents to be appropriate for the other distinct categories. This Miscellaneous category represents a significant portion of the total accidents, 110 out of 983 accidents. In this category, a third of the accidents would have been positively or likely positively influenced by the safety properties of the HGST, as shown in Figure 8.

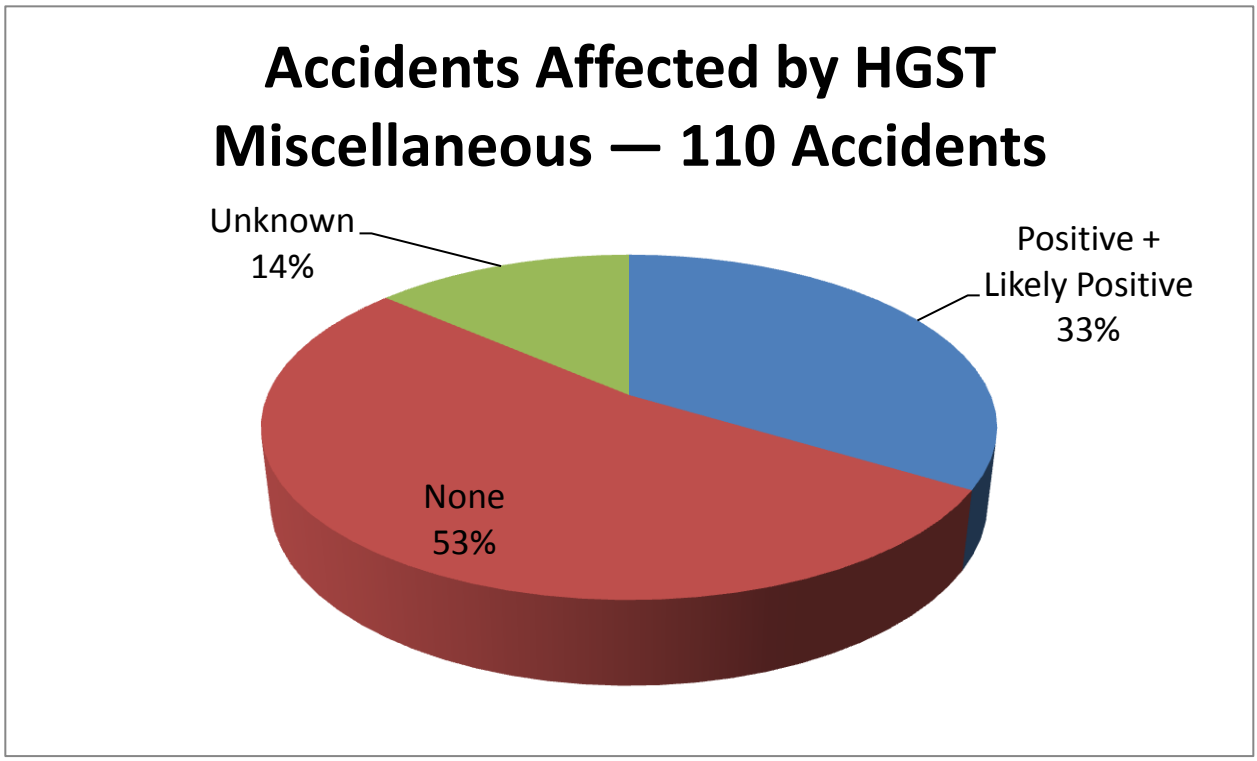


Figure 8 HGST Influence on Accidents in the Miscellaneous Category

The distribution of Safety Properties in the Miscellaneous category is shown in Figure 9. It is immediately apparent that the same Safety Properties that are prevalent in the preceding Takeoff and Landing and Loss-of-Control categories are also prevalent in this category.

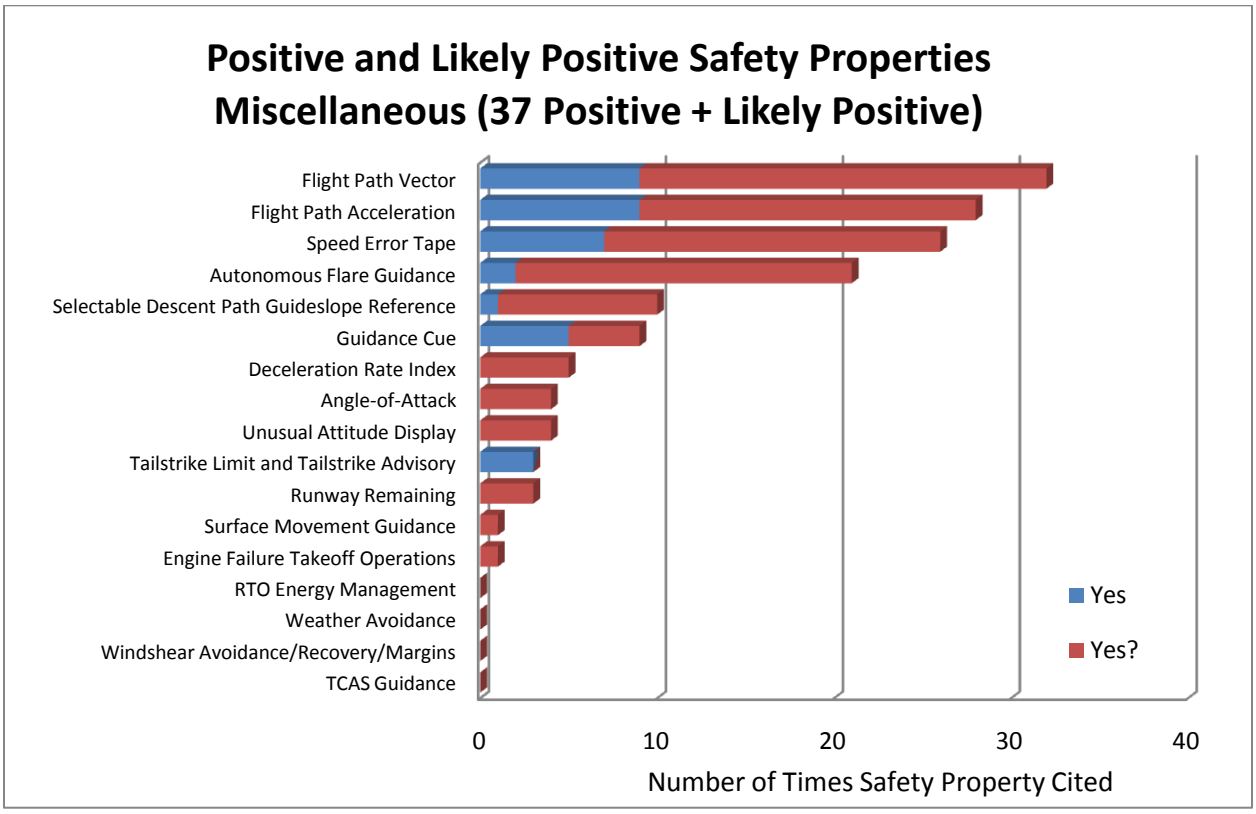


Figure 9 Ranking of Safety Property Influence for Miscellaneous Category Accidents

Two examples of the narratives of accidents in this category follow.

> "During the landing roll on Runway 18 (L or R?) at Pusan, the aircraft veered to the side and ran off the runway. After leaving the runway the aircraft ran into a drainage ditch between the two runways and its left main undercarriage collapsed allowing the left propeller to strike the ground. The accident happened in daylight (0939L) and in VMC; wind 130deg./16kt. The aircraft was operating a flight (JJA502) from Jeju. It is understood that, after the accident, the pilot had claimed that the brakes and rudder had appeared to be ineffective. According to unconfirmed reports, after take-off from Jeju, the 'rudder hydraulic caution light' had come on intermittently. The aircraft's handling did not seem to be effected and, after discussing the problem with the company engineering department, the pilot elected to continue to Pusan. During the descent into Pusan the elevator feel caution light is also said to have come on intermittently."
>
> While in normal cruise flight at FL270, one of the windshields cracked and the crew decided to depressurize the aircraft. They put on their oxygen masks but were reportedly unable to obtain any oxygen and lost consciousness. Meanwhile the aircraft had started to descend and entered a steep dive. The crew regained consciousness as the aircraft descended and were able to recover

from the dive. They subsequently elected to divert to Cape Girardeau where a safe landing was made sometime later. The accident happened in daylight (1030L) and in VMC.A subsequent inspection of the aircraft found that about 2/3 of the left horizontal stabilizer and 2/3 of the left and right elevator had separated and both wings were wrinkled. The oxygen system apparently worked when it was functionally tested in accordance with Airplane Flight Manual.

5.5 Propulsion Accidents

The category of accidents classified as propulsion-related accidents is considerably smaller in number than the previous categories of accidents. The proportion of accidents in this category that would have been positively affected by the HGST is also smaller. Less than 20% of the 48 accidents would have been positively or likely positively affected by the HGST, as shown in Figure 10.

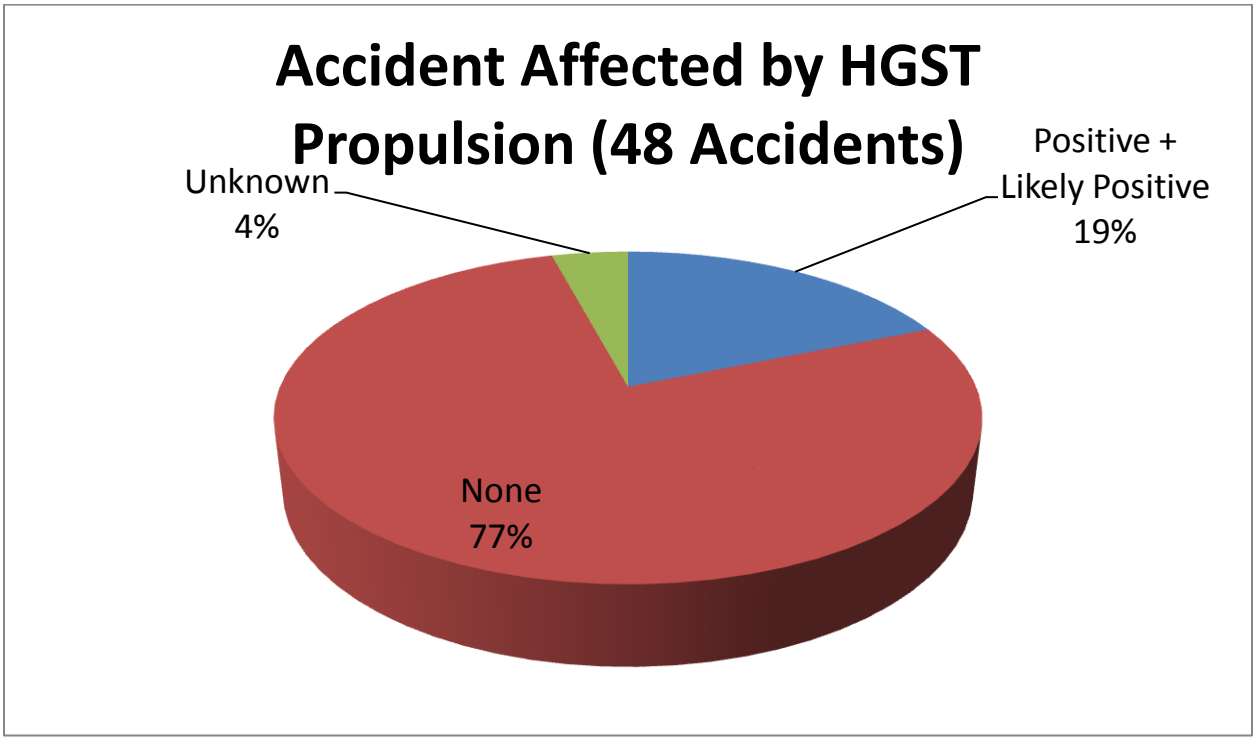


Figure 10 HGST Influence on Propulsion Accidents

Nevertheless, the same top Safety Properties again appear at the top of the list of properties in Figure 11.

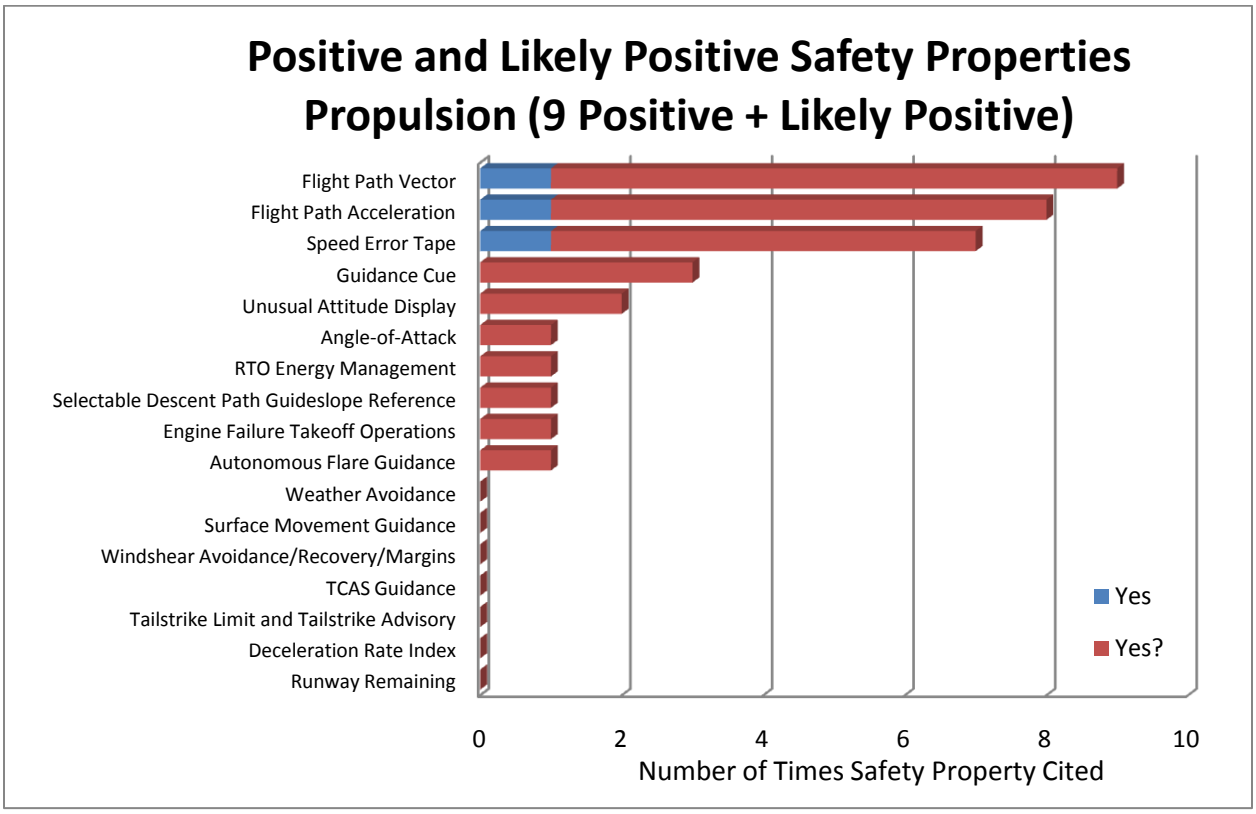


Figure 11 Ranking of Safety Property Influence for Propulsion Accidents

A couple of examples of the narratives associated with propulsion accidents follows.

> "While en route between Tehran and Khorramabad and in normal cruise flight at 18,000ft, the aircraft's No.2 engine reportedly began to lose power and shut down. The pilot elected to divert to Araak; however, during the landing roll, directional control was apparently lost and the aircraft ran off the side of the runway. The accident happened in daylight (1910L). It is understood that one area under investigation is the possibility of engine icing. It is reported that the aircraft was flying in cloud without the anti-icing system activated when the engine began to lose power.
>
> It is reported that on take-off from Lokichoggio, just after rotation, the aircraft encountered a flock of birds. The aircraft suffered multiple bird strikes with birds apparently being ingested into both engines. Power was lost and the aircraft touched down on the remaining runway length. The aircraft subsequently overran across rough ground and through trees. During the overrun the aircraft's nose and right main undercarriage failed and collapsed. After coming to rest leaking fuel caught fire and the aircraft was destroyed. The accident happened in daylight and in VMC. Wind easterly at 14kt."

5.6 Undercarriage Accidents

Accidents resulting from problems with the undercarriage comprise a relatively large set of accidents, although the portion that would be affected by the HGST safety properties is relatively small. As Figure 12 shows, there are 207 accidents in this category, but only 5 of these accidents were judged to be affected by the HGST safety properties. The safety properties that could have come into play are basically the same as those predominant in the previous categories.

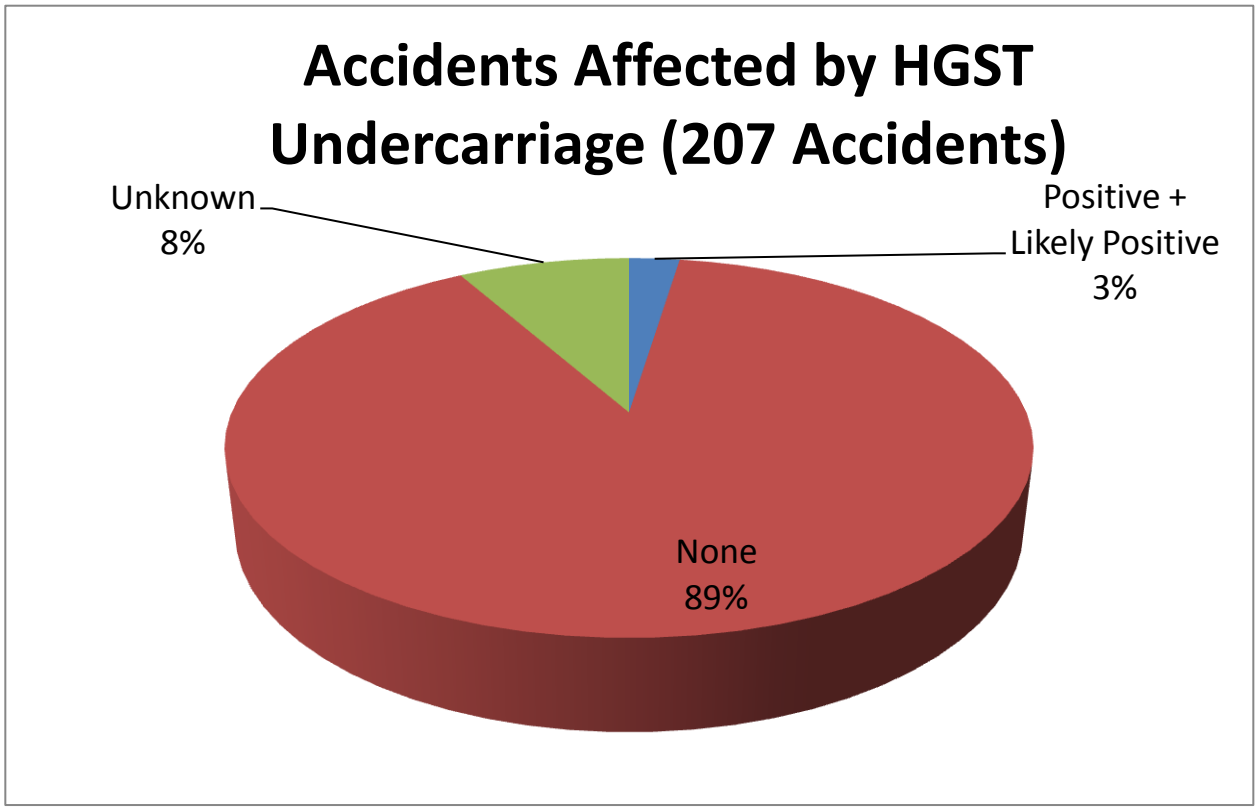


Figure 12 HGST Influence on Undercarriage Accidents

An example of the sort of accidents in this category is presented in the following narrative.

> "After departure from Houston, the co-pilot was unable to raise the undercarriage handle to retract the undercarrage. The crew discussed the problem and concluded that they 'did not have a landing gear malfunction, as there was no EICAS message.' They subsequently followed the 'Gear Lever Cannot be Moved Up' checklist in the QRH. The co-pilot engaged the undercarriage 'Downlock Release' button and the undercarriage retracted. The flight then continued to Washington. On approach to Dulles International Airport, Washington, when the crew selected the undercarriage down, a 'LG LEVER DISAG' message appeared on the EICAS. The crew flew a missed approach and attempted to troubleshoot the problem. They recycled the undercarriage several times but to no avail - when the undercarriage was retracted, everything seemed normal

but, when it was extended, the nose undercarriage failed to go down. They then carried out the Abnormal Landing Gear Extension Checklist, which included pulling the alternate undercarriage extension lever, but to no apparent effect. They subsequently carried out a fly-by of the control tower and ATC confirmed that, although the nose undercarriage doors were open, the nose undercarriage was retracted. The pilot declared an emergency before returning to Washington and landing with the nose undercarriage retracted. The aircraft came to rest on the runway where an emergency evacuation was carried out. Due to the attitude of the aircraft, a number of passengers and a flight attendant, who evacuated using the rear slides, sustained injuries while leaving the aircraft. The accident happened in daylight (2043L) and in VMC. The aircraft was operating a flight from Houston, Texas on behalf of United Express."

5.7 Environment, Mechanical Failure, Explosion and Fire, and Collision Accidents

The four remaining categories of accidents, Environment, Mechanical Failures, Explosion and Fire, and Collision accidents, were found to have little application of HGST safety properties. These accident categories were not generally very large. The following table shows the relative size of these categories:

Category	Number of Accidents	HGS Influence
Environment	50 accidents	1 likely positive
Mechanical Failure	17 accidents	0 HGST influence
Explosion and Fire	19 accidents	0 HGST influence
Collision	19 accidents	0 HGST influence

In aggregate, these four categories comprise less than 10% of the accidents in the study database. In general, these accidents were caused by events or situations out of the pilot's direct control and it is unlikely that they might have been influenced by HGST safety properties.

Conclusions

The HGST safety properties were found to be most effective in those areas where the pilot was directly involved. Coincidentally, those accident categories comprised the greatest number of accidents. Specifically, the Takeoff and Landing and Loss-of-Control categories combined represent almost half of the accidents in the study. When the Miscellaneous category is included, that total consists of 574 accidents, or 58% of the total accidents. The influence of the HGST can be seen in the following table of accident categories, number of accidents within the category, and the number of accidents affected by the HGST.

Accident Category	Number of Accidents	Accidents Affected by HGST
Takeoff & Landing	341 accidents	237 (69%) affected by HGST
Loss-of-Control	123 accidents	70 (57%) affected by HGST
Miscellaneous	110 accidents	37 (33%) affected by HGST

Focusing on these three areas specifically, the HGST would have positively or likely positively influenced 344 out of 584 accidents, or 59% of the accidents in the combination of these three categories.

Appendix A – Aircraft Included in the Study

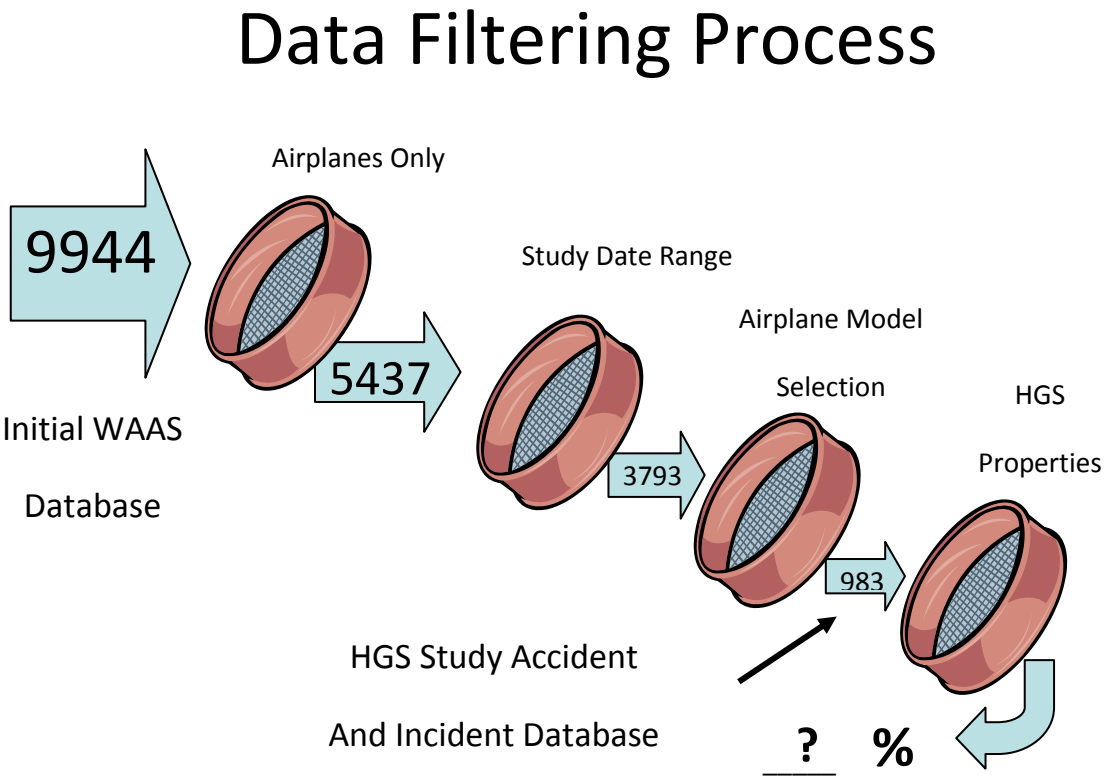
Airbus A310-200
Airbus A310-300
Airbus A319-100
Airbus A320-210
Airbus A320-230
Airbus A321-110
Airbus A321-130
Airbus A321-210
Airbus A321-230
Airbus A330-200
Airbus A330-300
Airbus A340-200
Airbus A340-310
Airbus A340-500
Airbus A340-600
Antonov An-124
Antonov An-124-100
Antonov An-140
Antonov An-140-100
Antonov An-32
Antonov An-32A
Antonov An-32B
Antonov An-38-100
Antonov An-70
Antonov An-72
Antonov An-72-100
Antonov An-74-200
Antonov An-74T-200
Antonov An-74TK-200
ATR-72-200F
ATR-42-300
ATR-42-500
ATR-72-200
ATR-72-210
ATR-72-500
Avro RJ100
Avro RJ70
Avro RJ85
B.Ae. Jetstream 31
B.Ae. Jetstream 32
B.Ae. Jetstream 41
B.Ae. Jetstream Super 31
Beech 200 King Air
Beech 200C King Air
Beech 200T King Air
Beech 300 King Air
Beech 300LW King Air
Beech 350 King Air
Beech 350C King Air
Beech A200 King Air
Beech B200 King Air
Beech B200C King Air
Beech B300 King Air
Beech Commuter 1900C
Beech Commuter 1900C-1
Beech Commuter 1900D
Beechjet 400
Beriev BE200ChS
Boeing 717-200
Boeing 737-300
Boeing 737-300F
Boeing 737-400
Boeing 737-500
Boeing 737-600
Boeing 737-700
Boeing 737-800
Boeing 747-300
Boeing 747-400
Boeing 747-400ER
Boeing 747-400F
Boeing 747-400M
Boeing 747-400SF
Boeing 757-200
Boeing 757-200PF
Boeing 757-300
Boeing 767-200
Boeing 767-200EM
Boeing 767-200ER
Boeing 767-300ER
Boeing 777-200ER
Boeing 777-300
Bombardier Global 5000
Bombardier Global Express
British Aerospace 146-100
British Aerospace 146-200
British Aerospace 146-300
British Aerospace ATP
Canadair Challenger 600
Canadair Challenger 601-3R
Canadair Challenger 604
Canadair RJ 100
Canadair RJ 100LR
Canadair RJ 200
Canadair RJ 200LR
Canadair RJ 440
Canadair RJ Challenger 800
Cessna 550 Citation Bravo
Cessna 550 Citation II
Cessna 551 Citation II/SP
Cessna 560 Citation Encore
Cessna 560 Citation Excel
Cessna 560 Citation Ultra
Cessna 560 Citation V
Cessna 650 Citation III
Cessna 650 Citation VII
Cessna 660 Citation VI
Cessna 750 Citation X
Dassault Falcon 2000
Dassault Falcon 50
Dassault Falcon 900
DHC Dash 7
DHC Dash 8-100
DHC Dash 8-300
DHC Dash 8-400
Dornier 228-100
Dornier 228-200
Dornier 328-100
Douglas MD-11
Douglas MD-11F
Douglas MD-81

Douglas MD-82
Douglas MD-83
Douglas MD-90-30
Embraer 170
Embraer 170 SE
Embraer 170 SU
Embraer 190 LR
Embraer 195
Embraer EMB-120 Brasilia
Embraer ERJ-135 Legacy 60
Embraer ERJ-135ER
Embraer ERJ-135LR
Embraer ERJ-145ER
Embraer ERJ-145LU
Fairchild SA-227AC Metro 23
Fairchild/Dornier 328Jet
Fokker 100
Fokker 50
Fokker 70
GA Gulfstream IV
GA Gulfstream IVSP
GA Gulfstream V
IAI 1125 Astra SP
IAI 1125 Astra SPX
IAI Gulfstream G100
Ilyushin Il-114F
Ilyushin Il-86
IPTN 212-100
IPTN CN-235-100
Learjet 40
Learjet 45
Learjet 55
Learjet 60
Mitsubishi Mu-300 Diamond 1
Mitsubishi Mu-300 Diamond 1A
Peregrine PJ-2
Premier I
SAAB 2000
Saab 340A
Saab 340B
Short 360
Shorts 360-300
Sino Swearingen SJ30-2

Appendix B – Aircraft Excluded from the Study

ASTA Nomad
Aerocar
Aerospatiale Corvette
Aerospatiale Caravel
Airbus A300
Antonov 2/12/24/26, 26B, 28
Augusta SF 600
DC-3/4/6/8/10
Nimrod
BAC 111
Concord
King Air 100
Boeing 707/727/
737-200, 737-200 Adv., 737-200C, 737-200C Adv., 737-200F Adv., 737-200QC
747- 100/200/SP
C-17
Bristol 170
BA HS 125
CL 44
CASA 212
CN 235
CJ 1/2/3
C206/207/210/406
Commander 500/1000/ 690/980
Catalina
Cessna 500 Citation I
Cessna 500 Citation I/SP
Cessna 501 Citation I
Cessna 501 Citation I/SP
Eagle II
Convair 240/340/440/580
Curtis C46
Falcon 10/20/200
Beaver
Buffalo
Twin Otter
Dornier 128
DO 28D2
EMB 110/121/711/720
Excel Jet
Fairchild C123K
F-27
FH 227
Fairchild 226 Merlin
Fairchild Metro
SA 22/26A/26T
Fokker F27/28
Gulfstream G1/G2
GA 1159A Gulfstream III
Albatross
Mallard
Harbin Y-12
Hawker 125/748
Hansa
IAI 1124 Westwind
IL 18/38/62/76
Lear 23/24/25/35
Let 410
Lisvnov Li2
Lockheed 100
Lockheed Tristar 1011
Lockheed Jetstar
Lockheed 188 Electra
Lockheed C-130
P2V/P3
Mitsubishi MU2
NAMC YS11
Parenavia AP68 TP 300
BN Islander
Piaggio 180
PC 6/12
PA 23 Aztec
PA 31
Saberliner 75
SAC Y-8
Shorts 330
Tupolev 134/154
Vickers 700 Viscounts
Xian Yun 7-100
Yak 40/42

Appendix C – Data Filtering Process



Appendix D – Personnel

The personnel listed below performed the contracted study.

- **Robert Vandel** Foundation Fellow and retired FSF Executive Vice President
- **Earl F. Weener, Ph.D.** FSF Foundation Fellow; retired Boeing Commercial Airplanes Chief Engineer