Head-up Guidance System Technology (HGST) — A Powerful Tool for Accident Prevention

Executive Summary

This project report (FSF/SP-91/01), "Head-up Guidance System Technology (HGST) — A Powerful Tool for Accident Prevention," is based upon a contracted study completed by Flight Safety Foundation in late 1990. In that study, the Foundation concludes that civil jet transport aircraft equipped with properly functioning head-up guidance system technology (HGST), that provides critical aircraft flight guidance and performance information to a correctly trained flight crew, will result in significantly fewer aircraft accidents, which will reduce loss of life. FSF advocates the use of this technology, which has only become available in recent years, because it offers aircraft operators an excellent tool to substantially reduce crew error, to which approximately 70 percent of fatal civil jet transport aircraft accidents is attributed.

The Foundation study of historic accident data suggests a substantial number of the civil jet transport accidents that occurred between 1959 and 1989 might have been prevented or positively influenced, if HGST had been available and properly utilized. A total of 543 total loss accidents and 536 major partial loss accidents are analyzed in the study to determine the potential of HGST to improve civil jet transport safety in takeoff/departure, descent/approach/landing, and en route phases of flight.

Specifically, the Foundation concludes that HGST might have prevented or positively influenced the outcome of 31 percent of the accidents. It also determines that HGST could probably not have prevented 56 percent of them. Insufficient information is available to reach a reasonable conclusion about the influence HGST might have had in the remaining 13 percent of the accidents.

These conclusions are presented not as absolute certainties, but as reasonable estimates based upon a subjective analysis of the available information.

Introduction

FSF undertook the study with the knowledge that accident causal factors show a persistent pattern. Based upon accident statistics, crew error is associated with approximately 70 percent of worldwide civil jet transport accidents; sometimes these errors occur in combination with other factors, such as poor weather or malfunctioning equipment.

Crew decision-making is influenced by the information available at any given time. Safety improvements are possible in many areas, but the greatest leverage, in terms of improving civil jet transport safety, lies in reducing the likelihood of crew error. Additional resources must be provided to aid crew responses to unexpected or difficult circumstances during those phases of flight where the flight situation changes rapidly, and therefore, where the risk is greatest, i.e., takeoff/climb and descent/approach/landing.

Today, HGST represents more than three decades of development beginning with the basic head-up display (HUD). HGST can provide direct economic benefit by permitting landing and takeoff in low visibility and in poor weather, and the technology is currently utilized by some civil airlines. However, until now, its potential to improve safety has not been analyzed in depth.

HGST [see Appendix A for detailed description of technology presumed in the study] allows the pilot, while looking through the windshield, to view simultaneously critical flight information, other traffic and the flight environment. HGST offers a decided advantage when compared to looking at panel-mounted flight instruments below the windshield, which calls for a downward movement of the head and a shift in eye focus during the transition from the panel-mounted instruments to visual contact through the windshield, especially in the demanding phases of flight addressed in the study.

In addition to providing pilots with enhanced situational awareness through a single presentation of information critical to safe flight, HGST provides the potential for maintenance of instrument flying skills, because they can be exercised regularly on each approach, landing and departure even in visual meteorological conditions.

Methodology

Each civil jet transport total loss accident and major partial loss accident, that occurred between 1959 and 1989 for which data were available, was reviewed to determine whether HGST might have altered the outcome of the flight. Some accidents were eliminated from detailed consideration because insufficient information on causal factors was not readily available for the study.

In-house resources and readily available outside resources were used for the accident reviews. Information was provided by government, industry and insurers.

The accident reviews are divided into two primary categories:

- Total Loss Accidents
- Major Partial Loss Accidents

This is done both for ease of analysis and because, as the results indicate, the causes of these accidents can be very different; combining data from the two categories could have led to misleading conclusions.

Each primary category is divided into three subcategories:

- Takeoff/Climb Accidents
- Descent/Approach/Landing Accidents
- Other/En Route Accidents

The subcategories are in accordance with accident statistics that confirm air transport accidents occur much more frequently during the Takeoff/Climb and Descent/Approach/Landing phases of flight, than while aircraft are en route at cruise altitudes. Consequently, passengers and crew are exposed to much greater risk during these relatively short and critical periods when rapid and frequent changes in flight performance and conditions often occur.

The study was performed using accident categorization forms for each subcategory [Appendix B]. These forms allowed for sufficient information to justify the conclusions, but information was brief enough to expedite analysis.

After each accident was reviewed and analyzed, it was subjectively rated whether HGST might have aided the pilot to have prevented or positively influenced the accident outcome. The rating system is defined as follows:

Yes: It is nearly certain that HGST might have aided the pilot.

Yes(?): It is probable that HGST might have aided the pilot.

No(?): It is not probable that HGST could have aided the pilot, but not enough information is known to be nearly certain.

No: It is nearly certain that HGST could not have aided the pilot.

☐ Insufficient information is available to reach a reasonable conclusion about the influence HGST might have had in this accident.

The ratings are combined into three groups to classify data in the "Analysis and Results" section. The groups are defined as follows:

Yes/Yes(?) There is a reasonable certainty that HGST might have prevented or positively influenced the outcome of these accidents.

No/No(?) There is a reasonable certainty that HGST could not have prevented or positively influenced the outcome of these accidents.

☐ Insufficient information is available to reach a reasonable conclusion about the influence HGST might have had in these accidents.

Takeoff/Climb Accidents

The specific data entered on the Takeoff/Climb Accident Categorization Form include: type of landing aid(s) available; windshear; icing; wet runway; snow or rain; low visibility or darkness; control surface configuration; control surface inoperative; over- or under-rotation; weight or balance problem; engine failure; tire failure; brake failure; electrical power loss or instrument loss; rejected takeoff (RTO); controlled flight into terrain (CFIT); other/notes; and a box for subjective rating.

The following factors in Takeoff/Climb Accidents might have been positively influenced by HGST:

- Rejected takeoff, with engine power loss well before V_1
- Windshear, wind gust, heavy rain, engine or airframe icing, wake vortex
- Engine power loss (but not power loss on all engines)
- Over- or under-rotation; flap configuration
- Pilot loses control of aircraft while airborne, but aircraft, in principle, is flyable
- Electrical power or instrument loss

Descent/Approach/Landing Accidents

The specific data entered on the Descent/Approach/Landing Accident Categorization Form include: type of landing aid(s) available; flight phase (approach, final approach, go-around or landing); CFIT; land long; land short or off-center; land hard; landing roll problems; windshear; high wind/crosswinds/gusting; wet runway; low visibility; snow or rain; darkness; type of approach (precision or non-precision); mechanical problem; navigational error or disorientation; midair collision or runway collision; emergency landing; other/notes;

and a box for subjective rating.

The following factors in Descent/Approach/Landing Accidents might have been positively influenced by HGST:

- CFIT after instrument landing system (ILS) is acquired or could have been acquired
- CFIT with airport visible, even without ILS (e.g., "black-hole" approaches)
- Windshear on final approach
- Electrical power loss or instrument loss
- Emergency landing
- Landing short, long, offside or hard

Other/En Route Accidents

The specific data entered on the Other/En Route Accident Categorization Form include: mid-air collision; radar environment; non-radar environment; CFIT; mechanical; weather; on-board fire; system failure; flight management system (FMS); other/notes; and a box for subjective rating.

Analysis and Results

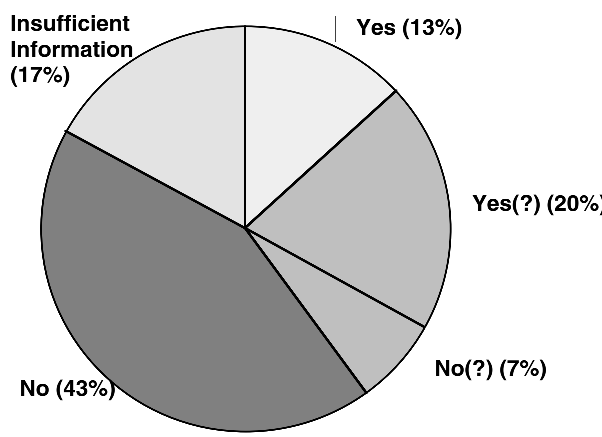
Total Loss Accidents by Occurrences

All Total Loss Accidents

The results summary of all Total Loss Accidents in the Takeoff/Climb, Descent/Approach/Landing and Other/En Route subcategories is presented in Figure 3-1.

Of 543 Total Loss Accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in 33 percent of them; and a reasonable certainty that HGST could not have prevented or positively influenced 50 percent of them. Insufficient information is available to reach a reasonable conclusion in the remaining 17 percent. The data are further refined by examining each subcategory and those results are presented in Figure 3-2.

Occurrences
All Total Loss Accidents



HGST might have prevented or positively influenced the outcome in 33 percent of All Total Loss Accidents.

Figure 3-1

Takeoff/Climb Total Loss Accidents

The results of the analysis of Takeoff/Climb

Occurrences

Total Loss Accidents by Subcategory

	Yes	Yes(?)	No(?)	No	Insufficient Information
Takeoff/Climb	16	38	13	65	32
Descent/Approach/Landing	56	69	21	138	52
Other/En Route	0	2	3	31	7

543 Total Loss Accidents are divided into three subcategories for rating.

Figure 3-2

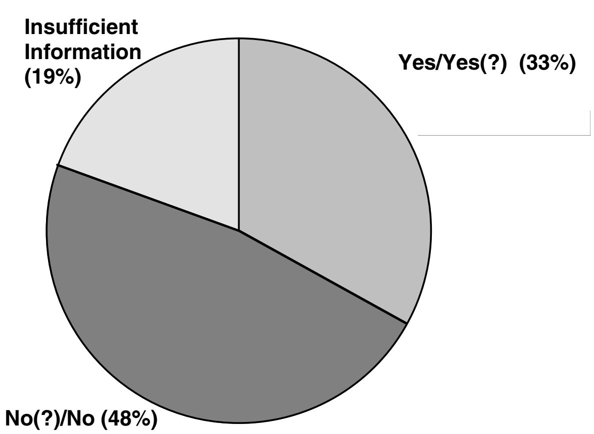
Total Loss Accidents are presented in Figure 3-3.

Of 164 Takeoff/Climb Accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in 33 percent of them; a reasonable certainty that HGST could not have prevented 48 percent of them; and insufficient information is available to reach a reasonable conclusion in the remaining 19 percent.

After completion of the analysis of this subcategory, several factors are identified that occur more frequently than others. These factors determine how the accidents are rated; they also suggest areas where HGST may be most beneficial.

Occurrences

Takeoff/Climb Total Loss Accidents



HGST might have prevented or positively affected the outcome in 33 percent of the Takeoff/Climb Total Loss Accidents.

Figure 3-3

Of the 54 Yes/Yes(?) accidents, 30 percent occur in conditions of low visibility or darkness. Engine failure or simulated engine failure plays a role in 24 percent of them. A minimum of 41 percent of them involve crew error. Frequent factors include recoverable engine failure and training error.

Of the 78 No(?)/No accidents, 19 percent occur during low visibility or darkness. Engine failure or simulated engine failure plays a role in 26 percent of them. A minimum of 17 percent of them involve crew error. Frequent factors include midair collision, runway collision, tire failure, bird strike, irrecoverable engine failure, mechanical problem, control surface problem, sabotage, and training.

Insufficient information is available to reach a reasonable conclusion in 32 accidents.

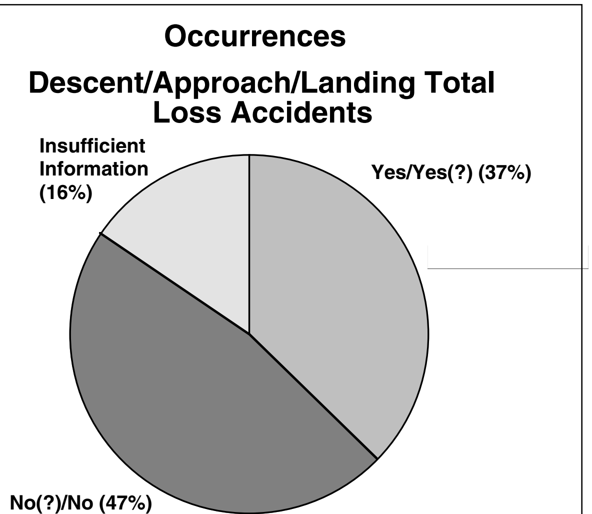
Descent/Approach/Landing Total Loss Accidents

The results of the analysis of Descent/Approach/Landing Total Loss Accidents are presented in Figure 3-4.

Of 336 Descent/Approach/Landing Accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in 37 percent of them; a reasonable certainty that HGST could not have prevented 47 percent of them; and insufficient information is available to reach a reasonable conclusion in 16 percent of them.

After completion of the analysis of this subcategory, several factors are identified that occur more frequently than others. These factors determine how the accidents are rated; they also suggest areas where HGST might be most beneficial.

Of the 125 Yes/Yes(?) accidents, 58 percent occur during Landing and 35 percent occur during Approach and Final Approach. Low visibility or darkness is present in 56 percent of the accidents. Short landing is a factor in 34 percent; long landing or off-center landing is



HGST might have prevented or positively influenced the outcome in 37 percent of the Descent/Approach/Landing Total Loss Accidents.

Figure 3-4

a factor in 21 percent; and hard landing is a factor in 16 percent. Rain or snow is present in 34 percent of the accidents. Frequent factors are nose gear failure or main gear failure caused by hard landing, altitude misjudgment, descent below minimums, low visibility and improper airspeed control.

Of the 159 No(?)/No accidents, 36 percent occur during Landing and 31 percent occur during Approach and Final Approach. Low visibility or darkness is present in 38 percent of the accidents. Short landing is a factor in 14 percent; long landing or off-center landing is a factor in 10 percent; and hard landing is not a factor in this subcategory. Rain or snow is present in 16 percent of the accidents. CFIT occurs in 21 percent of the accidents. Frequent factors are structural failure, runway collision, improper procedure and CFIT.

Insufficient information is available to reach a reasonable conclusion in 52 accidents.

Other/En Route Total Loss Accidents

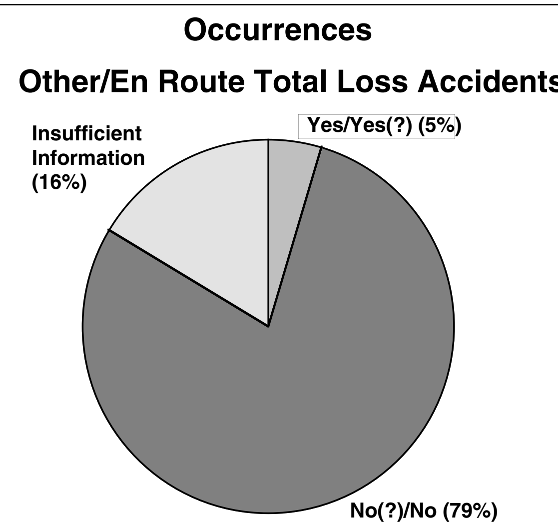
The results of the analysis of Other/En Route Total Loss Accidents are presented in Figure 3-5.

Of 43 Other/En Route Accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in five percent of the accidents; a reasonable certainty that HGST could not have prevented 79 percent of them; and insufficient information is available to reach a reasonable conclusion in 16 percent of them.

After completion of the analysis of this subcategory, few factors are identified that could be subject to the positive influences of HGST; the outcome of the majority of the accidents in this group could not have been influenced by HGST. The two Yes/Yes(?) accidents involve severe turbulence and both are scored Yes(?).

Of the 34 No(?)/No accidents, there are no factors collected on the categorization forms that suggest a discernible pattern, but some factors that are not collected on the categorization form did recur. Sabotage is a key element in 35 percent of the accidents. Violence, such as being forced to land or being shot down, is a factor in 18 percent of the accidents. Nine percent of the accidents occur as the result of major structural failure.

Insufficient information is available to reach a reasonable conclusion in seven accidents.



HGST might have prevented or positively influenced the outcome in five percent of the Other/En Route Total Loss Accidents.

Figure 3-5

Total Loss Accidents by Fatalities

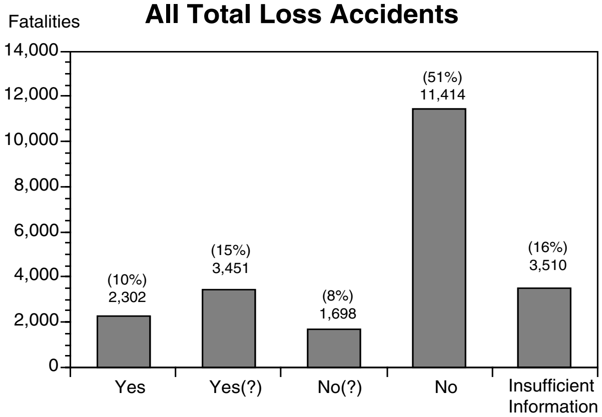
All Total Loss Accidents

An analysis of the number of fatalities that occur in these accidents is made to estimate how many fatalities might have been prevented by the use of HGST. The combined totals of all fatalities in the Takeoff/Climb, Descent/Approach/Landing and Other/En Route subcategories are presented in Figure 3-6.

There is a reasonable certainty that HGST might have prevented or positively influenced the outcome of the accidents which cause 25 percent of the fatalities; a reasonable certainty that HGST could not have prevented the accidents which cause 59 percent of the fatalities; and insufficient information is available to reach a reasonable conclusion about the accidents which cause 16 percent of the fatalities (Figure 3-7).

Fatalities

All Total Loss Accidents



HGST might have prevented or positively influenced the outcome in 5,753 (25 percent) of the 22,375 fatalities that occurred in All Total Loss Accidents.

Figure 3-6

Takeoff/Climb Total Loss Accidents

The results of the review of fatalities in this subcategory are presented in Figure 3-8.

Of 6,938 fatalities, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome of the accidents which cause 28 percent of the fatalities; a reasonable certainty that HGST could not have prevented the accidents which cause 46 percent of the fatalities; and insufficient information is available to reach a reasonable conclusion in the accidents which cause 26 percent of the fatalities. Accidents with more than 150 fatalities are noted

Fatalities

All Total Loss Accidents by Subcategory

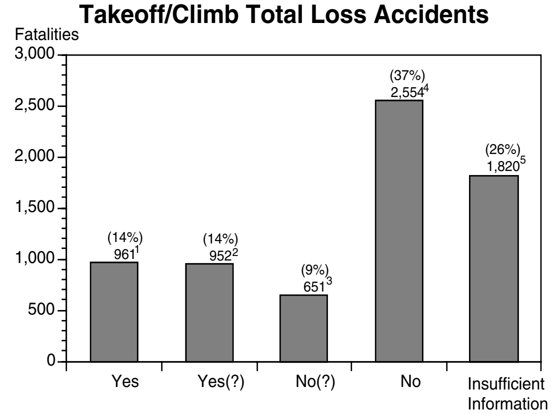
	Yes	Yes(?)	No(?)	No	Insufficient Information
Takeoff/Climb	961	952	651	2,554	1,820
Descent/Approach/Landing	1,341	2,333	611	6,014	1,392
Other/En Route	0	166	436	2,846	298

The 22,375 fatalities that occurred in the accidents are rated by subcategory.

Figure 3-7

Fatalities

Takeoff/Climb Total Loss Accidents

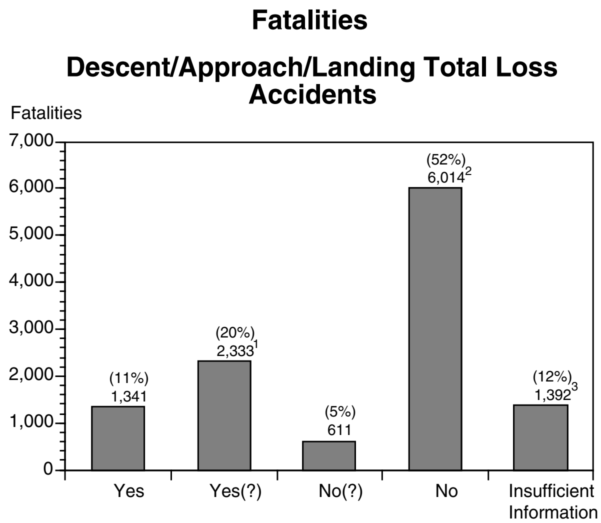


Accidents with More Than 150 Fatalities

1 - One accident with 155 fatalities, another with 213 fatalities.
2 - One accident with 271 fatalities, another with 155 fatalities.
3 - One accident with 520 fatalities.
4 - One accident with 301 fatalities, others with 156, 248, 346, 156.
5 - One accident with 256 fatalities, another with 163 fatalities.

HGST might have prevented or positively influenced the outcome in 28 percent of the fatalities in the Takeoff/Climb Total Loss Accidents.

Figure 3-8



Accidents witn More Than 150 Fatalities

1 - One accident with 175 fatalities, others with 181, 180, 183.
2 - One accident with 159 fatalities, others with 183, 154, 188, 191, 171.
3 - One accident with 174 fatalities.

HGST might have prevented or positively influenced the outcome in 31 percent of the fatalities that occur during Descent/Approach/Landing Total Loss Accidents.

Figure 3-9

in Figure 3-8.

All these fatalities occur in 116 accidents, but the 12 accidents with more than 150 fatalities each account for 42 percent of the fatalities.

Descent/Approach/Landing Total Loss Accidents

Results of the review of fatalities in this subcategory are presented in Figure 3-9.

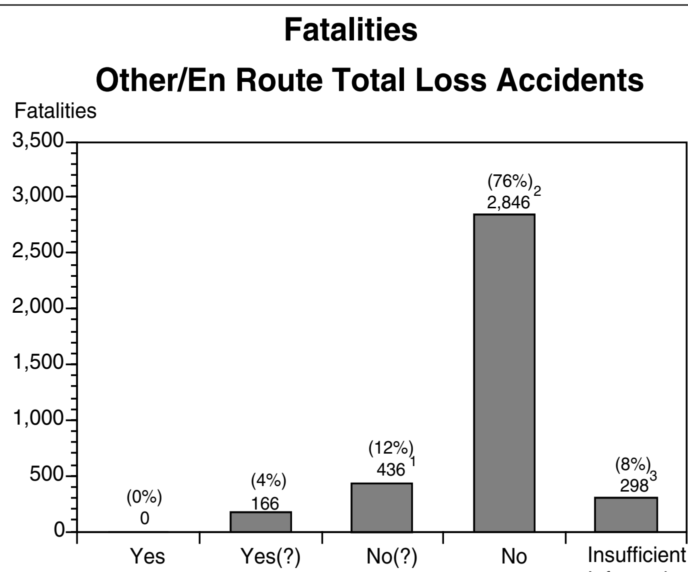
Of 11,691 fatalities, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in the accidents which caused 31 percent of the fatalities; there is a reasonable certainty that HGST could not have prevented the accidents which caused 57 percent of the fatalities; and insufficient information is available to reach a reasonable conclusion in the accidents which caused 12 percent of the fatalities. Accidents with more than 150 fatalities are noted in Figure 3-9.

All these fatalities occur in 221 accidents, but the 11 accidents with more than 150 fatalities each account for 16 percent of the fatalities.

Other/En Route Total Loss Accidents

Results of the review of fatalities in this subcategory are presented in Figure 3-10.

Of 3,746 fatalities, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in the accidents which cause four percent of the fatalities; a reasonable certainty that HGST could not have prevented the accidents which cause 88 percent of the fatalities; and insufficient information is available to reach a reasonable conclusion in the accidents which cause eight percent of the fatalities. There are fatalities in each of these 43 accidents, and there are several with more than 150 fatalities each.



Accidents with More Than 150 Fatalities

1 - One accident with 257 fatalities, another with 162.
2 - One accident with 170 fatalities, others with 261, 290, 167, 329, 269.
3 - One accident with 173 fatalities.

HGST might have prevented or positively influenced the outcome in four percent of the fatalities that occur during Other/En Route Total Loss Accidents.

Figure 3-10

Total Loss Accidents by Region

All Total Loss Accidents

Total Loss Accidents by Region presents the potential influence of HGST by subcategories in specific regions of the world. Total results of all regions are presented in Figure 3-11. [See Appendix C for explanation of how regions are defined for the purpose of this report.]

There is reason to believe that several regions of the world, including the U.S.S.R., Eastern Europe and the People's Republic of China have not reported all civil jet transport accidents that occurred during the 1959-1989 period. Therefore, the results of this analysis are skewed.

Region

All Total Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	22	27	8	55	8
Central America & Caribbean	3	4	0	13	10
South America	13	7	10	24	12
Western Europe	3	13	2	35	13
Scandinavia	0	3	0	1	0
Eastern Europe	1	7	1	14	1
Middle East	7	9	4	14	7
Africa	8	14	2	31	12
U.S.S.R.	0	3	1	11	18
Indian subcontinent	5	6	3	6	4
Southeast Asia	2	2	1	8	1
Asia	2	6	2	8	1
Pacific	6	8	2	13	4
Antarctica/Australia/New Zealand	0	0	1	1	0

Figure 3-11

Takeoff/Climb Total Loss Accidents

The results of the review and analysis of this subcategory are presented in Figure 3-12.

Region

Takeoff/Climb Total Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	6	14	4	23	2
Central America & Caribbean	1	0	0	2	3
South America	1	2	4	9	4
Western Europe	0	7	1	12	4
Scandinavia	0	2	0	1	0
Eastern Europe	0	1	1	1	1
Middle East	2	2	2	3	1
Africa	3	4	0	6	2
U.S.S.R.	0	3	0	1	10
Indian subcontinent	2	1	0	2	2
Southeast Asia	0	0	0	1	0
Asia	1	1	0	3	1
Pacific	0	1	1	0	2
Antarctica/Australia/New Zealand	0	0	0	1	0

Figure 3-12

The majority of the accident reports from the U.S.S.R. provide insufficient information to reach a reasonable conclusion in this subcategory. North America reports the greatest number of Takeoff/Climb Total Loss Accidents.

Descent/Approach/Landing Total Loss Accidents

The results of the review and analysis of this category are presented in Figure 3-13. North America reports the greatest number of accidents.

Other/En Route Total Loss Accidents

The results of the review and analysis of this subcategory are presented in Figure 3-14. The majority of the accidents in every region were rated in the No column.

Region

Descent/Approach/Landing Total Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	16	12	4	28	5
Central America & Caribbean	2	4	0	9	7
South America	12	5	6	15	8
Western Europe	3	6	0	18	6
Scandinavia	0	1	0	0	0
Eastern Europe	1	6	0	9	0
Middle East	5	7	2	7	6
Africa	5	10	2	22	9
U.S.S.R.	0	0	1	7	7
Indian subcontinent	3	5	3	4	2
Southeast Asia	2	2	1	5	1
Asia	1	5	1	3	0
Pacific	6	6	1	11	1
Antarctica/Australia/New Zealand	0	0	0	0	0

Figure 3-13

Region

Other/En Route Total Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	0	1	0	4	1
Central America & Caribbean	0	0	0	2	0
South America	0	0	0	0	0
Western Europe	0	0	1	5	3
Scandinavia	0	0	0	0	0
Eastern Europe	0	0	0	4	0
Middle East	0	0	0	4	0
Africa	0	0	0	3	1
U.S.S.R.	0	0	0	3	1
Indian subcontinent	0	0	0	0	0
Southeast Asia	0	0	0	2	0
Asia	0	0	1	2	0
Pacific	0	1	0	2	1
Antarctica/Australia/New Zealand	0	0	1	0	0

Figure 3-14

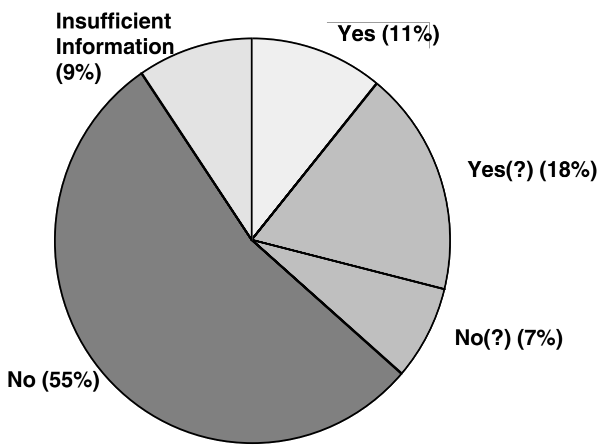
(* There is no Figure 3-15)

Major Partial Loss Accidents by Occurrences

All Major Partial Loss Accidents

The results summary of all Major Partial Loss Accidents in the subcategories of Takeoff/Climb, Descent/Approach/Landing and Other/En Route are presented in Figure 3-16.

Occurrences
Major Partial Loss Accidents



HGST might have prevented or positively influenced the outcome in 29 percent of all Major Partial Loss Accidents.

Figure 3-16

Of 536 Major Partial Loss Accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in 29 percent of them; a reasonable certainty that HGST could not have prevented 62 percent of them; and insufficient information is available to reach a reasonable conclusion in nine percent of them. Major Partial Loss Accidents are rated by subcategory in Figure 3-17.

Occurrences
Major Partial Loss Accidents by Subcategory

	Yes	Yes(?)	No(?)	No	Insufficient Information
Takeoff/Climb	2	0	8	84	9
Descent/Approach/Landing	56	95	31	178	40
Other/En Route	0	2	1	29	1

536 Major Partial Loss Accidents are rated by subcategories.

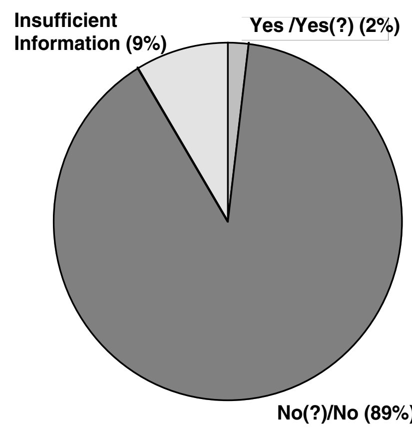
Figure 3-17

Takeoff/Climb Major Partial Loss Accidents

The results of the review and analysis of this subcategory are presented in Figure 3-18.

Of 103 accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in two percent of them; a reasonable certainty that HGST could not have prevented 89 percent of them; and insufficient information is available to reach a reasonable conclusion in nine percent of them.

Occurrences
Takeoff/Climb Major Partial Loss Accidents



HGST might have prevented or positively influenced the outcome in two percent of the Takeoff/Climb Major Partial Loss Accidents.

Figure 3-18

After completion of the analysis of this subcategory, several factors are identified that occur more frequently than others. These factors determine how the accidents are rated; they also suggest areas where HGST might be most beneficial.

Of the Yes/Yes(?) accidents, there are too few (two) accidents to reach a reasonable conclusion.

Of the 92 No(?)/No accidents, 43 percent occur during conditions of engine failure or simulated engine failure; tire failure is a factor in 11 percent of the them; and landing gear failure is a factor in eight percent of them. Frequent accident factors include engine failure, premature retraction of landing gear and structural failure of landing gear or airframe.

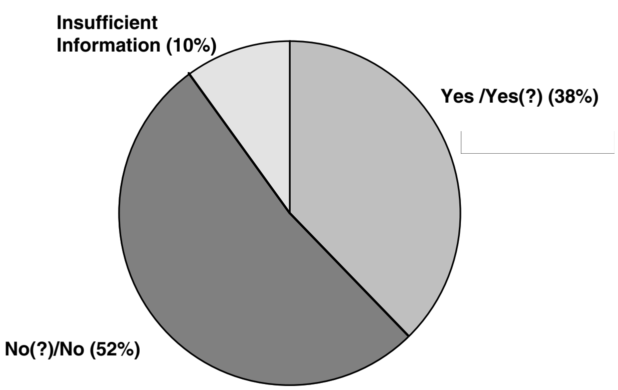
Insufficient information is available to reach a reasonable conclusion in nine accidents.

Descent/Approach/Landing Major Partial Loss Accidents

The results of the analysis of accidents in this subcategory are presented in Figure 3-19.

Of 400 accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in 38 percent of them; a reasonable certainty that HGS could not have prevented 52 percent of them; and insufficient information is available to reach a reasonable conclusion in 10 percent of them.

Occurrences
Descent/Approach/Landing Major Partial Loss Accidents



HGST might have prevented or positively influenced the outcome in 38 percent of the Descent/Approach/Landing Major Partial Loss Accidents.

Figure 3-19

After completion of the analysis of this subcategory, several factors are identified that occur more frequently than others. These factors determine how the accidents are rated; they also suggest areas where HGST might be most beneficial.

Of the 151 Yes/Yes(?) accidents, 83 percent occur during Landing. Low visibility or darkness is present in 33 percent of the accidents. Short landing is involved in 25 percent of the accidents; long landing or off-center landing is involved in 28 percent of them; and hard landing is involved in 30 percent of them. Rain or snow is present in 35 percent of the accidents. Frequent factors include fast landing which causes runway overrun; hard landing which damages landing gear or airframe; and visibility problems.

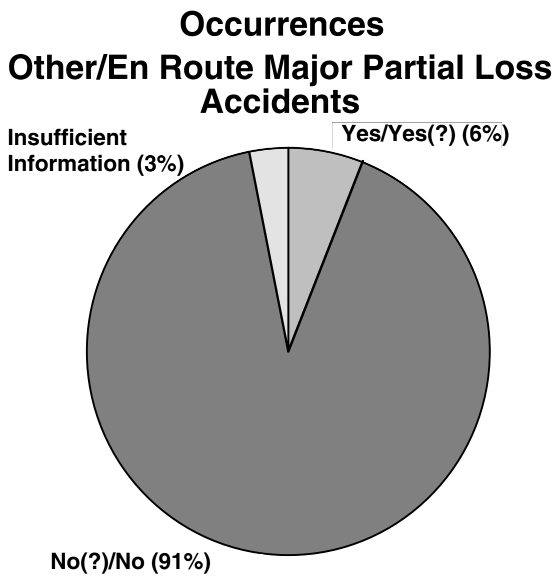
Of the 209 No(?)/No accidents, 83 percent occur during Landing. Mechanical problems are involved in 45 percent of the accidents. Landing gear failure (mechanical or crew error), accounts for 49 percent of the accidents. Frequent accident factors include engine failure, landing gear or airframe failure, and crew error related to landing gear.

Insufficient information is available to reach a reasonable conclusion in 40 accidents.

Other/En Route Major Partial Loss Accidents

The results of the analysis of accidents in this subcategory are presented in Figure 3-20.

Of 33 accidents, there is a reasonable certainty that HGST might have prevented or positively influenced the outcome in six percent of the accidents; a reasonable certainty that HGS could not have prevented 91 percent of them; and insufficient information is available to reach a



HGST might have prevented or positively Influenced the outcome in six percent of the Other/En Route Major Partial Loss Accidents.

Figure 3-20

reasonable conclusion in three percent of them.

After the analysis of this subcategory, few factors are identified that would be subject to the positive influences of HGST and the outcome of the majority of the accidents in this group could not have been influenced by HGST.

The two Yes/Yes(?) accidents are too few to reach a reasonable conclusion.

Of the 30 No(?)/No accidents, there are no factors on the Accident Categorization Form which fall into a discernible pattern, although some factors do recur. Engine failure plays a role in 33 percent of the accidents. Crew error is present in a minimum of 15 percent of the accidents. Frequent accident factors include structural damage, exploding engine, volcanic ash and weather.

Insufficient information is available to reach a reasonable conclusion in one accident.

Major Partial Loss Accidents By Fatalities

All Major Partial Loss Accidents

There are too few fatalities in this category to allow a significant analysis.

Major Partial Loss Accidents by Region

Major Partial Loss Accidents

All Major Partial Loss Accidents are rated by region. Results are presented in Figure 3-21; they are skewed, because some regions of the world report their accidents with less detail and accuracy than others.

Takeoff/Climb Major Partial Loss Accidents

Results of the review and analysis of this subcategory are presented in Figure 3-22.

The majority of the accidents in all regions are rated No. There are significantly greater numbers of accidents in North America and Western Europe, which probably reflect a greater number of flights in those regions.

Descent/Approach/Landing Major Partial Loss Accidents

Results of the review and analysis of this subcategory are presented in Figure 3-23.

Region
All Major Partial Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	27	32	15	119	11
Central America & Caribbean	5	7	1	16	2
South America	7	14	4	18	3
Western Europe	5	17	7	60	13
Scandinavia	0	1	2	0	0
Eastern Europe	2	1	2	5	1
Middle East	5	4	2	11	8
Africa	1	10	0	16	3
U.S.S.R.	0	0	0	1	0
Indian subcontinent	2	2	0	10	2
Southeast Asia	1	3	1	1	0
Asia	0	0	1	10	2
Pacific	3	6	5	20	5
Antarctica/Australia/New Zealand	0	0	0	4	0

Figure 3-21

Region
Descent/Approach/Landing Major Partial Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	26	30	11	75	9
Central America & Caribbean	5	7	1	12	2
South America	7	14	4	9	3
Western Europe	5	17	7	37	9
Scandinavia	0	1	2	0	0
Eastern Europe	2	1	0	4	1
Middle East	4	4	2	7	6
Africa	1	10	0	10	3
U.S.S.R.	0	0	0	1	0
Indian subcontinent	2	2	0	7	2
Southeast Asia	1	3	1	1	0
Asia	0	0	0	7	2
Pacific	3	6	3	6	3
Antarctica/Australia/New Zealand	0	0	0	2	0

Figure 3-23

Other/En Route Major Partial Loss Accidents

The results of the review of Other/En Route Major Partial Loss Accidents are shown in Figure 3-24.

The majority of the accidents in all regions are rated No.

Region
Takeoff/Climb Major Partial Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	1	0	4	30	2
Central America & Caribbean	0	0	0	4	0
South America	0	0	0	8	0
Western Europe	0	0	1	18	3
Scandinavia	0	0	0	0	0
Eastern Europe	0	0	1	1	0
Middle East	1	0	0	2	2
Africa	0	0	0	6	0
U.S.S.R.	0	0	0	0	0
Indian subcontinent	0	0	0	3	0
Southeast Asia	0	0	0	2	0
Asia	0	0	1	1	0
Pacific	0	0	1	7	2
Antarctica/Australia/New Zealand	0	0	0	2	0

Figure 3-22

Region
Other/En Route Major Partial Loss Accidents

	Yes	Yes(?)	No(?)	No	Insufficient Information
North America	0	2	0	14	0
Central America & Caribbean	0	0	0	0	0
South America	0	0	0	1	0
Western Europe	0	0	0	5	1
Scandinavia	0	0	0	0	0
Eastern Europe	0	0	0	0	0
Middle East	0	0	0	2	0
Africa	0	0	0	0	0
U.S.S.R.	0	0	0	0	0
Indian subcontinent	0	0	0	0	0
Southeast Asia	0	0	0	0	0
Asia	0	0	0	0	0
Pacific	0	0	1	7	0
Antarctica/Australia/New Zealand	0	0	0	0	0

Figure 3-24

Narratives of 12 incidents which might have been prevented by HGST are presented in reverse chronological order.

1. On August 22, 1979, a Boeing 727 encountered a heavy rainshower with associated windshear during final approach to Hartsfield International Airport in Atlanta, Georgia, U.S. The aircraft descended to less than 375 feet above ground level (agl) before it exited the shower and initiated a successful missed approach. The U.S. National Transportation Safety Board (NTSB) determined that the incident's probable cause was the unavailability to the crew of timely information concerning a rapidly changing weather environment along the instrument landing system (ILS) final approach course. The unavailability of this data resulted in an inadvertent encounter with a localized rainshower and associated windshears which required the crew to use extreme recovery procedures to avoid an accident. A contributing factor was a lack of equipment for the airport terminal area that could have detected, monitored and provided quantitative measurements of windshear both above and outside the airport's boundaries. There was no damage to the aircraft; there were no injuries to passengers or crew.

2. On July 11, 1976, during an ILS approach to Sendai, Japan, a Boeing 727 descended out of clouds at an altitude of 250 feet agl and subsequently touched down on the right main landing gear. The right wing tip, right leading edge slat, outboard trailing flap and fairings were damaged. The flight crew was unaware that the aircraft had been damaged during the landing; there were no injuries to passengers or crew.

3. On March 16, 1976, the pilot-in-command of a Boeing 727 lost visibility after touchdown due to heavy rain. The aircraft ran off the side of the runway, but the pilot taxied the aircraft to the terminal. The aircraft sustained minor damage to the landing gear and the trailing edge flaps, and there were no injuries to passengers or crew.

4. On March 4, 1976, during an ILS approach to runway 13 at New York/La Guardia, a Boeing 727 descended from clouds to the left of the runway, at an altitude of 250 feet agl. The pilot-in-command banked the aircraft to the right and then to the left to align the aircraft with the runway. The aircraft touched down on the left main landing gear. The left wing tip, left leading edge flap, outboard trailing flap and fairings were damaged. The flight crew was unaware that the aircraft had been damaged during the landing; there were no injuries to passengers or crew.

5. On September 3, 1974, during a coupled ILS approach in instrument meteorological conditions to Nairobi Airport (elevation 5,327 feet) in Kenya, the altitude selector was set to 5,000 feet; a descent to capture this altitude was initiated. The Boeing 747 aircraft descended through the cleared altitude (7,500 feet) just before it became established on the localizer. Although the aircraft was below the glideslope, the descent was continued until the ground was sighted at 200 feet agl. During the subsequent overshoot maneuver, the aircraft flew within 70 feet of the ground at a distance of approximately 6.75 nautical miles (nm) from the airport.

   The incident was caused by the pilots' acceptance of an altitude to which they mistakenly believed the aircraft had been cleared to descend, which was below the level of the surrounding terrain. Contributing factors were the failure of the air traffic controller to challenge the incorrect readback of the descent clearance; inadequate crew monitoring; the relatively high speed of the aircraft's approach; and crew sickness. There was no damage to the aircraft; there were no injuries to passengers or crew.

6. On July 31, 1973, a DC-9 was executing a backcourse localizer approach to runway 02 at Chattanooga/Lovell Field Airport in

Tennessee, U.S. The aircraft was still airborne approximately 4,000 feet past the threshold of the runway, which is 7,400 feet in length. The aircraft landed approximately 1,200 feet before the end of the runway. The aircraft continued off the end of the runway in a right turn, executed by the pilot-in-command in an attempt to avoid approach lights. The aircraft slid through the mud sideways for 420 feet and the left main landing gear collapsed. The aircraft came to rest on the left wing, right main gear and nose gear. There were no injuries to passengers and crew, and there was only minor damage to the aircraft. The weather was 400 feet scattered, 4,700 feet overcast, visibility one mile in light rain, fog and smoke. The minimum visibility required for the approach was one mile.

7. On May 9, 1973, tower personnel observed a DC-10 in an extreme nose-high attitude as it contacted the runway. Following contact with the ground, parts were observed to fall from the tail section, followed by the tail cone separating from the airframe at the two lower hinge attach points. Investigation disclosed that the two hinges were dragged on the runway for 86 feet. Both hinges were abraded sufficiently so that the tail cone became separated at the lower section and struck the two inboard elevators. Investigation disclosed this model aircraft did not have a tail skid. Damage required replacement of the tail section and two elevators. The crew was unaware of the damage until the tower advised them of the incident. There were no injuries to passengers or crew.

8. On April 10, 1973, a Boeing 727 struck trees while executing an instrument approach to runway 25 at the Toledo Express Airport in Toledo, Ohio, U.S. The incident occurred as the aircraft passed through a snow shower near the approach path to the airport. The instrument approach was abandoned and a second approach and landing were accomplished without further incident. Damage was limited to the leading edge and trailing edge flaps of the right wing. There were no injuries to passengers or crew. It was determined that the probable cause of the incident was the failure of the crew to adhere to established procedures, which resulted in a descent below the authorized minimum descent altitude and an impact with the trees.

9. On August 19, 1972, a Boeing 707 took off from Cologne, Germany, at 0115 hours bound for Istanbul. In the vicinity of Zabreb, Yugoslavia, at flight level 330, there was a failure of the number three engine. After clearance from Belgrade air traffic control (ATC), the aircraft descended to flight level 290. The flight requested permission to land at Sofia Airport due to the engine failure and fuel depletion.

The aircraft descended for landing, made a left turn about 15 kilometers southwest of the Sofia outer marker and the crew reported that the aircraft was established on the ILS. The crew then discovered a fire in the number four engine.

Sofia radar gave three course corrections to the pilot-in-command to return the aircraft to the centerline. The flight reacted slowly to the corrections. About two kilometers before touchdown, the pilot-in-command saw that the aircraft was well off the glide path and the runway was to the left. He elected to land, because the aircraft lacked sufficient fuel to go around, and two engines were inoperative.

The aircraft contacted the runway 101 meters from the threshhold, with its right wing tip and the number four engine. An additional 75 meters farther, the right landing gear contacted the runway; 130 meters farther the left landing gear contacted the runway. Tracks left on the runway by the aircraft's tires were at 235 degrees magnetic, i.e., a deviation about 40 degrees from the axis of the runway. After sliding about 150 meters, the aircraft left the runway, then started turning to the right to return to the center of the runway. There was minor damage to the aircraft and there were no injuries to passengers or crew.

10. On December 21, 1971, a Boeing 727 was flying from Charlotte, North Carolina, U.S. to Hartsfield International Airport, Atlanta, Georgia. An ILS approach to runway 9R to Category II minima was initiated with the automatic pilot and approach coupler engaged. The landing flaps were extended to the 30 degrees position when the aircraft passed over the outer marker. During flap extension, the aircraft deviated from the glideslope centerline and did not become established again on the glideslope, until it was approximately 800 feet agl. At 225 feet agl, the aircraft deviated again from the glideslope, and it began a descent that continued until the landing gear struck the approach lights. The aircraft was landed on the runway. There was minor damage to the aircraft; there were no injuries to passengers or crew.

It was determined that the probable cause of the accident was an unexpected and undetected divergence of the aircraft from the glideslope centerline induced by a malfunction of the automatic pilot. This divergence occurred at an altitude from which a safe recovery could have been made. However, both the pilot and first officer were preoccupied with establishing outside visual reference under visibility conditions which precluded adequate altitude assessment from external clues. Consequently, the pilot did not recognize the divergence from the glideslope in time to avoid contact with the approach lights.

11. On June 22, 1971, a DC-9 was on a flight from New Bedford, Massachusetts, U.S., to Martha's Vineyard, Massachusetts. While on a very high frequency omnidirectional range station (VOR) final approach to the airport, in instrument meteorological conditions, the aircraft struck the water, but remained airborne. The captain then flew the aircraft to Boston's Logan International Airport, where he made a normal landing.

The incident occurred at 0830 approximately three miles from the end of runway 24 at Martha's Vineyard. There was minor damage to the aircraft and there were no injuries to passengers or crew. It was determined that the probable cause of the incident was lack of crew coordination in monitoring the altitude during performance of a non-precision instrument approach, misreading of the altimeter by the captain and lack of altitude awareness by both pilots.

12. On December 13, 1969, a Boeing 747 was being ferried from Boeing Field in Seattle, Washington, U.S. During the approach to landing at Renton Airport, also in Washington, the aircraft struck an embankment approximately 20 feet short of the threshold of runway 15. The contact point was 30 inches below the top of the bank. The aircraft came to a stop on the centerline of the runway and 3,500 feet from the threshold. There was substantial damage to the aircraft; there were no injuries to passengers or crew.

Weather was scattered clouds at 4,500 feet and broken clouds at 6,500 feet. Visibility was 13 miles and the wind velocity was 20 knots from 120 degrees true. It was determined the probable cause of the incident was premature touchdown of the aircraft during a visual approach to a relatively short runway, induced by the pilots not establishing a glidepath, which would assure runway threshold passage with an adequate safety margin under somewhat unusual environmental and perceptual conditions.

Conclusions

Flight Safety Foundation concludes that HGST might have prevented or positively influenced a significant number of the civil jet transport accidents that occurred between 1959 and 1989, if the involved aircraft had been equipped with properly functioning HGST that was operated by a correctly trained crew. Such equipment presumed in this study, however, has become available only in recent years.

The greatest number of accidents occur during Descent/Approach/Landing and Takeoff/Climb, the two most critical phases of flight where HGST is most beneficial.

Thirty-three percent of All Total Loss Accidents might have been prevented or positively influenced by HGST. Analysis of Takeoff/Climb Total Loss Accidents indicates that 33 percent of them might have been prevented or positively influenced by HGST. Analysis of Descent/Approach/Landing Total Loss Accidents indicates that 37 percent of them might have been prevented or positively influenced by HGST. Analysis of Other/En Route Total Loss Accidents indicates that five percent of the accidents might have been prevented or positively influenced by HGST. (Refer to Figures 3-1 through 3-5.)

Twenty-nine percent of All Major Partial Loss Accidents might have been prevented or positively influenced by HGST. Analysis of Takeoff/Climb Major Partial Loss Accidents indicates that two percent of them might have been prevented or positively influenced by HGST. Analysis of Descent/Approach/Landing Major Partial Loss Accidents category indicates that 38 percent of them might have been prevented or positively influenced by HGST. Analysis of Other/En Route Major Partial Loss Accidents indicates that six percent of them might have been prevented or positively influenced by HGST. (Refer to Figures 3-16 through 3-20.)

Other technologies, applied in concert with HGST, such as ground proximity warning systems (GPWS) and image-enhancing radar, are likely to further reduce human error in Descent/Approach/Landing and Takeoff/Climb phases of flight, as well as in ground operations.

Implementation of any new technology can be accompanied by unforseen effects that, in some situations, can introduce new opportunities for error. Modern simulation capabilities, applied to new technologies, offer an additional resource to solve unforeseen problems, and real-world experiences are likely to contribute to further refinements of HGST.

Appendix A — Head-up Guidance System Technology

The contracted study completed by Flight Safety Foundation in late 1990, evaluates whether head-up guidance system technology might have prevented or positively influenced the outcome of civil jet transport accidents that occurred between 1959 and 1989.

The study considers 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 aircraft.

Head-up guidance equipment projects a holographic display on a glass combiner attached to the windshield. The display presents situation and guidance data. Symbology data are focused at infinity and more than 90 percent of the available light passes through the display from the windshield. The operating features of the head-up guidance equipment presumed for this study, were based upon current commercially available equipment for civil transport category aircraft and included the following:

- windshear detection and recovery guidance
- roll index
- indicated airspeed
- ground speed
- radio altimeter
- barometric altitude
- vertical speed
- DME (distance measuring equipment) data
- navigation and course guidance information
- localizer and glideslope data
- warnings and other information displayed against a horizon line marked in five-degree magnetic heading tick-marks and a pitch ladder marked in five-degree steps.

Also, flightpath vector data, which depicts where the aircraft is going based on its current flightpath, and inertial acceleration data, which depicts acceleration or deceleration of the aircraft, were also included as operating features.

In the instrument landing system (ILS) mode, the system is presumed to track the ILS and guide the pilot through a precision approach, flare and landing. In a visual approach and landing to an airport where ILS is not available, the aircraft's true inertial flight path is displayed and a head-up precision approach to a precise touchdown is made possible by an electronically constructed glideslope. Runway guidance is optimized to provide aircraft guidance information on the runway during takeoff roll and after touchdown.

Appendix B — Accident Categorization Forms

Takeoff/Climb Accident Categorization Form

Accidents						
landing aid						
windshear						
icing						
wet runway						
snow or rain						
night or low visibility						
control surface configuration						
control surface inoperative						
over or under rotation						
weight and balance						
engine failure						
tire failure						
brake failure						
electrical power or instrument loss						
rejected takeoff						
CFIT						
notes						
preventable by HGST?						

Descent/Approach/Landing Accident Categorization Form

Accidents						
landing aid						
flight phase						
CFIT						
land long						
land short or off-center						
land hard						
rollout problems						
windshear						
high, gusty or crosswinds						
wet runway						
low visibility						
snow, sleet rain						
darkness						
type of approach						
mechanical problems						
navigation error lost						
midair or collision on runway						
emergency landing						
notes						
preventable by HGST?						

	midair	radar environment	non-radar environment	CFIT	mechanical	weather	fire	system failure	FMS	notes	preventable by HGST?
Accidents											

Other/En Route Accident Categorization Form

Appendix C — Region Key

The following is a key to the regional indexing used in this report. The divisions are made geographically, not politically.

North America: Canada, continental United States (including Alaska)

Central America: Costa Rica, Guatemala, Honduras, Mexico, Panama

Caribbean: Antigua, Barbados, Bermuda, Cuba, Dominican Republic, Guadeloupe, Haiti, Montserrat, St. Lucia, U.S. Virgin Islands

South America: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Surinam, Venezuela

Western Europe: Austria, the Azores, the Balearics, Belgium, Denmark, England, France, Ireland, Italy, Luxembourg, Malta, The Netherlands, Portugal, Scotland, Spain, Switzerland, West Germany

Scandinavia: Norway, Sweden

Eastern Europe: Bulgaria, Czechoslovakia, East Germany, Greece, Poland, Romania, Yugoslavia

Middle East: Afghanistan, Bahrain, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates (UAE), Yemen

Africa: Algeria, Angola, Cameroon, Canary Islands, Egypt, Equatorial Guinea, Ethiopia, Gabon, Ghana, Guinea, Ivory Coast, Kenya, Liberia, Libya, Madagascar, Madeira Islands, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, South Africa, Sudan, Tangier, Tunisia, Zaire, Zambia

U.S.S.R.

Indian Subcontinent: India, Nepal, Pakistan, Sri Lanka

Southeast Asia: Burma, Cambodia, Malaysia, Singapore, Thailand, Vietnam

Asia: Hong Kong, Mongolia, People's Republic of China (PRC), South Korea, Taiwan

Pacific: American Samoa, Caroline Islands, Chejin Islands, Guam, Hawaii, Indonesia, Japan, Palau Islands, Philippines, Tahiti

Antarctica/Australia/New Zealand

Appendix D — Personnel

The personnel listed below performed the contracted study.

- Capt. Edward Arbon (retired, Trans World Airlines)
- Leonard Wojcik, Ph.D.
- Allen Mears
- Tania Calhoun

This project report (FSF/SP-91/01), "Head-up Guidance System Technology (HGST) — A Powerful Tool for Accident Prevention," based upon the contracted study, was produced by the following personnel:

- Roger Rozelle, FSF director of publications
- Ashton Alvis, FSF production coordinator