

The Remote Aircraft Flight Recorder and Advisory Telemetry System, RAFT (Patented), And It's Ability to Reduce fatal Air Accidents By 78%

1 While Enhancing Air Space Capacity, Operational Efficiency and Aircraft Security

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1. INTRODUCTION

RAFT is a worldwide, real-time aircraft remote monitoring and recording system that takes an aircraft's Digital Flight Data Recorder, DFDR, monitoring parameters out of an archival data base and plugs them into a safe, readily available, usable accident prevention system. RAFT combines the DFDR sensor data with the data from the Air Traffic Management/Control (ATM/C) system along with GPS/GLONASS, Map, Terrain and Weather information to actively anticipate and prevent accidents. It ends the information vacuum created by the aircraft and the ATM/C where presently each of them, acting independently, don't have sensors that directly measure the necessary parameters required to prevent a crash. By the sharing of the digital data, all of the necessary crash prevention parameters become visible and usable to actively anticipate and prevent problems from turning into fatal accidents. It opens the whole field of commercial aviation to the use of expert systems to minimize fatal accidents. Privileged non-safety related data is ciphered at the aircraft to insure air carrier confidentiality. In addition, the global telemetry of the DFDR parameters allows aircraft monitored data to be simply and safely stored on the ground. Thus making it readily available for aircraft statistical analysis programs that enhance air carrier efficiency and safety. Also, in the advent of a crash, it provides a timely accurate global estimate of the downed aircraft's location for search, recovery and hopefully rescue operations. It establishes an aircraft global data super highway that uses high bandwidth satellite and ground Internet communication links to supply the aircraft advisories necessary to enhance air space capacity, operational efficiency, security and reduce fatal accidents by seventy-eight percent.

RAFT brings to aviation what the Internet brought to data visibility and utilization. It unifies the National Airspace System (NAS) and fills the information vacuum that has been responsible for twenty years of a stagnant air carrier fatal accident rate. This information vacuum has seriously compromised the safety net and is the major cause of the stagnant air carrier fatal accident rate. It has also led to a situation where **currently air travel is over nine times more lethal than bus travel¹, over three times more lethal than car travel and over fifteen times more lethal than space shuttle travel.** RAFT makes all of the necessary safety data visible and readily available to the people who need to solve problems. It does this in a timely and cost effective manner, before they become fatal accidents. This is accomplished by reducing workloads while unambiguously enhancing the situation awareness. The present overly dependent verbal system, that is prone to fatal misinterpretations, is supplemented with visual safety emergency icons and physical synthetic vision representations of the situation. RAFT also provides functional redundancy, simplifies the communication system and enhances the safety and timely availability of the recorded data. It is the only system capable of meeting the national goal of reducing the fatal accident rate by a factor of five in ten years and provides the necessary safety net that should be put in place prior to any transition to free flight.

2. MAIN SECTION

2.1 BACKGROUND

More accidents can be attributed to aircraft data utilization than to stress and fatigue failures of the airframe. **The present federated airspace system is failing¹ to reduce the accident rate mainly because it presents the data too late, is prone to single thread failures, difficult to modify, costly and doesn't meet the needs of the new millennium.** On 9/26/97 there was a 234-fatality, Garuda Indonesia Airlines A-300 accident. The plane went into a mountain because the air traffic controller and pilot's verbal left right heading rotational instructions were confusing and misinterpreted. Other verbal errors also may have contributed to the accident. The information was being displayed via the air traffic control (ATC) radar blip or dot. At the instant time of the crash the dot disappeared from the screen. A screen dot contains no information as to the direction/rotation of an aircraft. Yet the direction of the aircraft is a DFDR parameter provided by the inertial navigation system (INS). If the aircraft along with the terrain had been depicted to the ATC, in a simple synthetic vision display that showed the actual aircraft correctly rotating, this accident wouldn't have occurred. This accident highlighted two basic problems with our present safety systems. The first being that the system is too dependent on voice communications, that can easily be misinterpreted or unintentionally given out erroneously. The second is that the system displays depend on inferences and are abstract. They don't utilize all of the data available to make them human friendly. Fortunately in this information age we can supplement the voice and radar blip displays with synthetic vision, human friendly presentations that increase the situation awareness and substantially reduce fatal accidents.

In the 1960s there was a very successful infusion of technology into the NAS —placement of the INS into commercial aircraft. The initial INS was inserted on the B-707 by Pan American Airlines. In order to prevent a single-thread failure and provide redundancies of this critical function, two INS were installed. The FAA required that two INS units be functional prior to takeoff. To mitigate the risk of a delay, if one of the INS experienced a problem prior to take off, a third INS was installed on the B-747. In a similar fashion the autopilot, like the INS, is now functionally redundant. These units now have a very high functional availability. For enhanced safety it is desirable to eliminate other single-thread functional failures by having at least dual redundancy for fatal accident prevention.

An example of single-thread failure is the 228-fatality crash of the Korean Airlines B-747 Flight 801 that occurred on 8/6/97 at Agana Guam. At the time of the accident the ATC tracking radar was working, but the glide slope unit was inoperative. With the loss of the glide slope radar, the plane's altitude was low resulting in a crash into a hill. The altimeter on the aircraft was working. In this instance, if the aircraft's altitude data had been cooperatively shared with the ATC tracking radar data and used in an integrated display, it could have provided a backup for the malfunctioning glide slope unit. The aircraft's glide slope display can be made transparent to the failed microwave system so that the pilot would not require a different presentation. Thus, by the cooperative sharing of the DFDR and ATC data in real-time, accidents like this can be avoided. Because of the major advancements in computers, memory and communications bandwidth and technology it is now possible to provide safety function redundancy at a fraction of the present federated system cost.

The present DFDR system is analogous to having a patient in intensive care being monitored. However few people look at the data until the patient dies or after release from the hospital. The DFDR is so important that in the advent of an ocean crash we risk lives and expend vast amounts of time and money searching for it. Even with these Herculean efforts the recovered DFDR's recorded data may be unreadable. After recovery of a readable DFDR, we utilize its data in a playback mode to perform a post-flight animation and analysis to determine the root cause of a crash. This is necessary to take a corrective action that will prevent the future reoccurrence of the

accident. The DFDR data is also routinely collected for post-flight statistical analysis. With six real-time programs that cooperatively share the DFDR and ATC data, about 78 percent of the fatal US air carrier crashes can be prevented. Post-flight analysis of non-crash data is still a reactive approach to flight safety, although some may marginally call it proactive. This important post-flight safety work, which can save up to 5 percent of the fatal accidents, is presently being carried out in the Flight Operational Quality Assurance (FOQA) program. **The big pay back in flight safety, as well as cost savings, does not come from post flight analysis but only comes from using this data in real-time application programs that are targeted at accident prevention. These real time programs that share safety data will result in a dramatic increases in air capacity, safety, security and operational efficiency.**

The present safety data vacuum, created by not sharing all of the sensors required in real-time to solve safety related problems, has been the major cause of the lack of reducing the air carrier fatal accident rate in over twenty years¹. This period represents two-thirds of the time that the NTSB has been in existence. With the growing use of air travel this translates to an ever-increasing number of unnecessary and presently preventable air fatalities. By the real time sharing of the digital safety data, all of the necessary crash prevention parameters become visible and usable to actively anticipate and prevent accidents. The flight crew is responsible for control of the aircraft and ATC is responsible for the airspace and airport areas. The flight crew and the controllers are in a codependent symbiotic cooperative relationship for the safety and economic benefit of the public. It is this relationship that brought radars to both the pilot and the air traffic controller's utilization. Therefore the system should aid in minimizing misunderstanding and expedite communication to minimize fatalities. Thus air travel is a cooperative synergistic enterprise between the flight operation centers, pilots and the air controllers that requires precise communication for safe transportation. Simple shared safety advisory icons, warning of problems, only inserted into displays when there are potential and existing problems, will significantly improve safety and situation awareness while decreasing work loads. These safety icons/alarms would only come on during potential and existing problems and thus would not clutter or distract from the normal ATC displays. At present, once alarms come on in a plane there is a lot of voice communication that takes place, between the flight crew and the traffic controllers, that can easily be misunderstood. It also puts stress on both the pilot and controller, depletes precious reaction time and increases their workloads. The 1/25/90 Avionca crash, that had 73 fatalities, is just one case of where communication problems under stressful conditions have led to fatalities. The Avionca plane ran out of fuel while in a ATC directed holding pattern over JFK Airport. The crew reported to the ATC that they were running out of fuel but did not use the word emergency. The FAA listed the cause of this fatal crash as pilot error. This syntactical mistake is no reason for people to die since a simple emergency low fuel safety icon can automatically be displayed on the ATC monitor, similar to the low fuel warning light on automobiles, to alert the controller of the dangerous low fuel status. The low fuel warning light or oil pressure warning lights in an automobile doesn't increase the driver's workload but simply increases the situation awareness and prevents catastrophic failures. Once a controller receives a low fuel warning light he can then set the landing priorities to expedite a safe landing. The fuel supply is another one of the DFDR parameters whose data is presently locked in the aircraft DFDR and thus the ATC doesn't have any visibility other than with voice communication with the aircraft that the fuel is low. The problem was not the crews voice communication, pilot error or the air controller but the present unforgiving system that shares its safety data begrudgingly and has been willing to sacrifice innocent people for simple and normal human errors. The lack of automatically sharing of cooperative safety data did not permit the controller to have an unambiguous situation awareness of the pre-crash emergency. The 8/6/97 Korean B-747 crash is also another case of the failure in the single thread, verbal communication system. The ATC could have continually verbally requested the aircraft's altitude from the flight crew and together with his radar range information successfully

verbally guided the plane down to a safe landing. Also if the aircraft's DFDR altitude data going to the DFDR was readily and automatically available to the ATC, it in combination with the ground radar could have easily provided an automatic back up for the malfunctioning glide slope radar. In the future, after RAFT is operational, and a 6/8/95 ValuJet type fire occurs, the fire and smoke sensors added to the plane and recorded in the DFDR, will light icons and sound alerts not only on the flight deck's displays but also on the air traffic controller's console. It is the controller's responsibility to assure that a plane that is or may be experiencing a critical flight problem on the ground is not cleared for a takeoff. Also that a plane experiencing a critical flight problem in the sky, is cleared for a safe landing in the shortest possible time. It is also important to alert the necessary ground support people to care for the passengers and flight crew so as to minimize further disasters. The present system is too verbally dependent in communication for the next millennium. Just as the internet is moving from just printed data to printed, graphics and acoustics; RAFT will permit the migration of the shared aviation system's safety information to move from essentially verbal communications to acoustic, graphic and printed. With the use of commonly shared visual icons as well as acoustic alerts the situation awareness of potential problems will be raised so as to prevent fatal accidents.

Another crash that could have been avoided with the RAFT system was the 9/2/98 Swissair, MD-11, flight 111 crash that killed 229 people. The plane left JFK Airport in NY and headed over the Atlantic towards Geneva, Switzerland. The pilot calmly made a "Pan, Pan, Pan" call telling the controllers that there was "smoke in the cockpit" and asking for a landing deviation "to a convenient place, I guess Boston." The controllers in Canada's Moncton Center suggested Halifax. In order to accomplish this the aircraft had to descend steeply. Although, the smoke in the cockpit wasn't bad enough to prevent this from occurring and the aircraft was capable of a steep descent the pilot decided to pass Halifax and circle back. After passing Halifax, while circling back, the plane went out of control and crashed at a high speed into the ocean. The pilot, in the present obsolete and antiquated system, is on his own. Many experts asked "Why didn't they pull the plug and bring the heavy laden trijet down quickly to a safe landing on the runway?" The flight recorders weren't working during the last six minutes of the flight, after it passed Halifax. There is some evidence that a fire existed in the entertainment wiring, but no one knows for sure what happened.

The RAFT real-time expert system would have prevented this fatal accident. It is no different than what we do for our astronauts in the space shuttle program. RAFT transmits the DFDR data in real-time to the ground, so that experts equipped with an aircraft simulation capability can provide the pilot with the safest way to handle this situation. Like the ValuJet debacle, there was plenty of time to bring the MD-11 down to land in Halifax. The vehicle had the capability to descend quicker and there was sufficient time to provide experts located on the ground to advise the pilot as to how best to handle the situation. The lack of a RAFT expert system hot line that had complete visibility to the control parameters being monitored on the plane, prevented the saving of these lives. Thus, unlike our astronauts, this pilot wasn't given any expert advice that included the benefits vehicle simulation. He was on his own, experiencing a situation that he had never encountered and 229 people died in a horrific crash. RAFT would have prevented this, and future situations in this class, from occurring. Too often we look to fix specific problems, via our traditional crash investigations. New problems will always emerge that can lead to fatal accidents. Fortunately in most cases there is sufficient time to bring a plane down to a safe landing. What's needed to substantially drop the fatal accident rate is a proactive real-time system that tackles whole classes of unanticipated problems before they become fatal accidents. Aircraft problems need not turn into fatal accidents. The lack of a real-time monitoring and a proactive system is the real cause of most fatal accidents. RAFT, on a global basis, prevents these aircraft problems from turning into fatal accidents.

2.2 DETAILED DESCRIPTION

RAFT is a worldwide real-time aircraft remote monitoring recording system that is used for enhancing airspace capacity, operational efficiency, passenger safety and security. It brings the digital flight data recorder information out of an archival database and plugs it into a real-time usable accident prevention system. It ends the information vacuum created between the aircraft and air traffic controller. Presently each is acting separately lacks the sensors to directly measure the necessary parameters required for preventing aircraft mishaps. Combining these data sensors enhances the effective sensor suite so that many events can be anticipated. This event anticipation capability provides the visibility and time mandatory for the prevention of accidents. A best estimate of the location of a downed aircraft for timely search, rescue and retrieval operations may be provided by linking the global telemetry of the DFDR parameters to a ground processing and distribution station.

RAFT updates the federated system and unifies the communications approach so that the relevant data parameters are globally visible and readily available for timely and cost-effective problem resolution. It is a system engineering approach that potentially can eliminate or minimize the need for the costly and time intensive recovery of the aircraft's recorder. An alternate is to keep the existing FDR and to use RAFT as a redundant system that essentially eliminates the need to recover, in all but a very small percentage of the crashes, the recorder. By so doing, it also eliminates the need to routinely post flight down load the recorder for FOQA data. The FOQA data will automatically and securely be disseminated, at essentially no cost, to the proper people. Thus RAFT alleviates a broad spectrum of problems. As time progresses, and RAFT proves its reliability over many years of service, the existing on-board FDR will atrophy (similar to Omega, Loran and sextant star fixing navigation equipment).

Twenty-four hours worth of DFDR data, for all of the US air carrier, taxi and cargo aircraft is not an insurmountable data quantity to be managed and can be contained on 32 gigabytes of disk space. This amount of data presently fits on only two personal computer (PC) disks. Because of the advances in information processing and communications technology, a modern airspace information system can be built that will effectively simplify the aircraft avionics and provide redundancy as well as add capability. One major advantage of this system is that it can provide routing, weather, map and topographical data while also providing redundancy.

RAFT remotes the DFDR and its communications system will integrate the ATC, air carrier dispatch and the aircraft into an integrated system that will reduce the number of aircraft LRUs while providing redundancy. The two-way data super highway can handle the information of the DFDR data transmitted from the aircraft to the ground. By balancing the uplink and downlink transmissions, it can also provide the communications pipeline for safety advisories, weather, terrain/map and differential GPS corrections transmitted from the ground to the aircraft. It is a total global system approach to the problem that is aimed at reducing maintenance, enhancing operational efficiency, and increasing air space capacity and safety. The following paragraphs, figures, and descriptions illustrate the advantages of RAFT system.

Figure 1 depicts the RAFT Avionics System. It shows an aircraft consisting of a sensor multiplexer transceiver, also called the sensor multiplexer receiver and transmitter (SMART), that receives the inputs from the aircraft's performance and control sensors. The GPS and/or GLONASS navigation satellite data, if available, are also other inputs into the SMART. The RAFT transceiver antennae radiates to a communications satellite the sensor data compiled from SMART along with cargo bay, passenger compartment, and cockpit video information, and acoustic data. SMART also

receives advisory data from the communications satellite, which is then shown on the Advisory Display System (ADS) panel located in the cockpit. Although Figure 1 depicts two antennae, it is possible to utilize only one antenna depending on the uplink and downlink frequency selected for the communications satellite. Although the figure shows separate LRUs for the display and data multiplexer functions, it is possible to utilize the existing LRUs aboard the aircraft, in multi-functional mode, for the RAFT displays.

Figure 2 depicts the worldwide communications link. It illustrates an aircraft communications with the nearest satellite and then the communications satellite link. The aircraft's data reception satellite then relays this data to other satellites in a line-of-sight communications data link until it reaches the closest satellite with an unobstructed data transmission path to the Central Ground Based Processing Station (CGBS). Communications is duplex, and thus the CGBS receives aircraft data and communicates with each aircraft or with all of the aircraft in the net simultaneously. Major safety data advisories in the form of cautions, warnings, and alerts are transmitted to the operating aircraft based on the ground processing of the information from the aircraft and ATC system. The ATC system consists of air traffic control radar and GPS surveillance data along with in-route weather information and map & topographical databases. These advisories are transmitted to the cockpit ADS as depicted in Figure 1.

Figure 3 depicts the CGBS. It shows the processed and stored data, aircraft simulators, aircraft advisory generators, display and control of the CGBS, and data transmission modules to the ATC, aircraft manufacturer, and air carriers. Because some of the data are air-carrier privileged, a number of the data parameters are ciphered at the aircraft's SMART so that only the air carrier has the encrypt keys. This is similar to the telecomputing banking and Internet charge card systems. The ground transmission of the data will utilize existing high band width fiber optic backbone communications links with capabilities of 45 to 155 million bits per second. These links are presently being used on the Internet.

Figure 4 depicts the Ground Based Distribution system. It shows the ground processor communicating with the map, topographic and weather data base systems. It also depicts the aircraft manufacture and air carrier communications links and the ATC/M communication system. RAFT encompasses both the Terminal Radar Approach Control (TRACON) and the En-route ATC/M functions.

Some other examples of accident occurrences relating to data deficiencies in the present ATC/M system are airport runway/ground incursions. The salient example of this type of accident occurred on 3/27/77 at Tenerife in the Canary Islands. Two Boeing 747s (KLH and Pan American) crashed head on along a runway killing 583 people. Although this accident occurred some 20 years ago its root cause still exists. Two recent examples of runway/ground incursions include (1) the 2/1/91 LAX, Los Angeles, CA ground collision where a US Air Boeing 737 landed on a Skywest Fairchild Metroliner that killed 34; and (2) the 12/3/90, Romulus, MI Northwest Boeing 727 and Northwest DC-9 runway incursion that killed 8. These runway/ground incursion killers can and will continue to occur unless RAFT is implemented to plug the hole in the information system. RAFT will alter the future ATC/M and CAS global displays. The current blip/point/dot plan position indicator (PPI) type radar displays, which are 1950 vintage carry over presentation technology, are incapable of showing the aircraft rotation. RAFT displays depict actual aircraft and shows the status of their brakes, landing gear, thrust, track, Euler angles; and a safe path or collision alert in a timely simple presentation. These new displays will decrease the flight deck and controller workload while increasing their situation awareness. The present blip/dot/point displays are ambiguous and as such require excessive interpretation and concentration to be utilized in future systems. They are incapable of meeting low fatal-accident rate criterion. Most of the current ATC and CAS physical displays can be programmed to RAFT compatible presentations. These will depict actual aircraft, terrain and map

data on simple human friendly displays that will increase the situation awareness of both the flight crew and traffic controllers while decreasing their workload. This physical representation of aircraft and terrain while minimizing the formerly ambiguous blip/point/dot displays is an excellent example of where the fusion of DFDR and ATC data simplifies human interface during routine and stressful operations.

Figure 3 and 4 combine to provide not only the ATC/M function but also a global weather and air turbulence reporting and advisory system for operational efficiency and safety. The most current weather maps, made available from government and flight operation center meteorology departments, are transmitted to the flight crew via the telemetry system. RAFT provides a global communication system so that the flight crew and the flight operational centers jointly makes routing decisions based on the best available weather and airport status data. The ATC/M are automatically informed and can participate in these critical decisions. Planes that are experiencing weather data anomalies, such as clear air turbulence and lightning, report their findings to the central ground based weather system in order to update the database. Decisions such as fuel remaining, distance to destination and aircraft location are automatically factored into the efficiency and control equation to assure safety. The ground processor performs the real time booking keeping effort to assure that an aircraft isn't following too closely into the clear air turbulence, disturbance, wake created by a preceding aircraft that was flying close to the same local trajectory. The computer keeps track of wake extinction coefficients by aircraft, derived analytically and experimentally, to assure that the proper time delay and safe separation distance are met. The weather data created in the flight deck is automatically time and position tagged. Since the system has all of the best data available, and a global wide bandwidth communication system, it can disseminate the information to all of the people who need to solve the weather and routing problems in a timely manner. Thus optimal decisions for the routing of an aircraft can be made.

Figure 5, Tenerife et al, Raft Provides Automated Collision Avoidance Alerts, ATC/M and CAS Enhanced Capability Display, generically shows the situation of the 583-fatality head on Tenerife collision. It illustrates two aircraft on a runway orthogonal to each other. Both aircraft have their thrust on, brakes off, and are heading for a collision. Due to the inability of the ATC to see that brakes are off, thrust on, or the possibility of a collision, a fatal accident could occur. The ATC under these conditions depends on voice communications with the pilots, which may be misinterpreted. RAFT because of its access to all of the parameters going to the flight recorder, can show the ATC the brakes, thrust, velocity, and heading of both of the planes in a simple graphic display as well as process the data to anticipate a collision. The map inputs to the system can provide the ATC with pictorial displays similar to those shown in Figure 5. The processor solves the estimated collision point long before it occurs and sends automated advisories/alerts that will enable the aircraft to take anti-collision maneuvers. Using RAFT the crash-avoidance advisories can be sent to the aircraft via manual as well as automated voice and ADS alerts. Working with air traffic controllers and pilots will optimize the exact colors of the displays utilized as well as the blinkers and human engineering crash prevention alerts. The pictorial data will be made to work with existing monochromatic displays; however, color monitors provide more human performance enhancements, are more user friendly, more effective, and are the current display technology.

Figure 6, Tenerife, et al., No More, Raft Provides A Safe Trajectory Display ATC/M & CAS Enhanced Capability, depicts a safe takeoff condition for the previous example. Here the display will show a green safe path for takeoff for the plane that has thrust on and is moving. The red aircraft at the cross-runway condition is stopped with brakes on and engine thrust low. The digital processor computes a safe trajectory, which is depicted by a safe trajectory arrow. This simple ATC display pictorial is an example of the type of display RAFT is capable of providing. With the existing radar, or even future GPS non-cooperative system, these accidents will continue to occur

since the ATC doesn't have access to the brake and thrust vectors that are recorded away in the DFDR. Using radar and/or GPS and differentiating the position vectors to get velocity and then differentiating again to get acceleration is both too noisy and time consuming to use for collision avoidance in the close encounter ground/runway incursions areas.

The conditions requiring a safe takeoff trajectory arrow are more complex than just the collision case. Clear air turbulence, weather, topographical and runway status, length, and icing conditions will be part of a safe-to-take-off simulation that takes into account the aircraft type, weight, etc. to arrive at a pilot advisory. The caution/warning safe-to-take-off advisories can be automatically sent to pilots on the ADS displays. Accidents such as the 3/22/92, Fokker F-28-MK4000, that crashed at the end of the runway at La Guardia Airport, Flushing, NY are too often attributed to pilot or controller error, but are in fact system breakdowns. The complex relationships required for take off under adverse conditions should be aided by a pre-takeoff computer simulation that advises the pilot of the probability of a successful take off on the ADS display. It is possible that the takeoff and landing safe algorithms will be time dependent since it may be important to alter the time between takeoffs to account for the air turbulence wakes generated by the preceding aircraft. Turbulence wake extinction coefficients could be used, or past history based on tests, may have to be used in the absence of active laser/microwave turbulence sensor data. The RAFT system aids the controller and prevents work over-loads by providing the bookkeeping of the time dependent operations and simple aircraft animated real-time visual displays.

The Avianca, 1/25/90, Boeing 707 accident that killed 73 in Cove Neck, NY as a result of an aircraft running out of fuel after being put into a holding pattern, is an example of where data being sent to the DFDR should be used in real-time. The ATC would have knowledge of the remaining fuel with its estimated flight time capability and not solely depend on voice communications. A fuel-remaining icon can flash on the ATC's display; for example, to indicate when an aircraft has only 15 minutes of fuel remaining. The fuel caution icon could be only illuminated during the low remaining fuel conditions and thus would not clutter the display during routine operations. The low fuel icon displayed on the ATC terminal would be similar to the low fuel warning light in an automobile. This Avianca accident was also attributed to pilot/first officer error when in reality the pre-RAFT existing federated, non-cooperative safety system was the cause of these fatalities.

In a similar fashion the fire monitors can have their alarms displayed simultaneously in the cockpit and as a fire icon on the ATC's display. This remote alarm capability is similar to many of the fire alarm systems installed in private residences, businesses and government buildings. This dual alarm system would have provided an early warning, followed by mitigating actions which would have prevented the Value Jet, Miami, 5/11/96, 100-fatality accident.

The entire class of Controlled Flight into Terrain (CFIT) is still another example of where RAFT will substantially reduce accidents. This is accomplished by terrain map databases uplinked to the cockpit for synthetic vision as well as the terrain map information superimposed on the ATC in air and runway displays. The displays will also show the aircraft animation and not just ambiguous dots to show their rotations. These displays can be simpler than the present blip/point/dot rotation displays. RAFT permits these high fidelity displays by way of its cooperative safety data sharing capability.

In addition the present airborne X-Band, 3 cm wave length weather radar sensor, which is capable of seeing objects in all weather, day and night, must get restored to its original multi-function mode. Even though CFIT has been responsible for a high percentage aviation fatalities (see TABLE 1), over the last thirty years the airborne radar has been allowed to atrophy from an anti-collision and weather capability to just a weather radar. This radar must be returned to its original multi-function mode of weather and surveillance. In the maritime industry it is the X-band radar that

provides the anti-collision capability for both boats and ships. The low cost X-band airborne radar, implemented via a modified control and display system, can eliminate almost all of the CFIT. This day and night, all weather, radar will provide the visibility of terrain to essentially eliminate CFIT fatal accidents such as the 8/6/97 Korean Airlines, B-747 Agana, Guam, the 4/3/96 US Air Force, B-737, Dubroynik, Croatia, the 12/20/95 American Airlines, B-757 (Cali) Buga, Columbia and the 9/27/97 Garuda Indonesia Airlines, A-300 Buah Nabar, Indonesia.

The X-band radar supplemented with runway corner reflectors will also provide a much higher signal strength robust landing system than the GPS stand alone versions. The stand alone GPS landing systems are too easily prone to navigation data outages. This is due to the GPS navigation receivers being susceptible to only nano-volt electro-magnetic interference from intentional jamming and unintentional man made or natural electro-magnetic L-band radiation noise sources. The aircraft's radar can also provide the robustness needed for Cat. I, II and III landing systems and combined with GPS and INS in a complementary filter system it will provide the required redundancy and high operational availability. There are even compelling arguments for keeping the present microwave Instrument Landing System (ILS) and integrating it with the other sensors to add more redundancy into this critical function. This complementary filter system will minimize the GPS deficiencies (e.g.: A one watt jammer - the size of pack of cigarettes- will render the GPS navigation signals useless for 25 miles. Four-watt GPS jammers that fit into the palm of your hand are now internationally available to render GPS useless for a 100-mile area.). Thus the X-band radar will add an all weather direct viewing rf visibility to the flight deck that enhances the crews visual perception to essentially eliminate CFIT. The information system would be supplemented with synthetic vision objects provided by map and terrain databases. The X-band radar, which can see both fixed and mobile targets, can be used to automatically register the synthetic visual system as well as to eliminate synthetic vision problems that result from faulty data bases or mobile objects. Thus the radar and data base map systems complement each other to enhance the optical visual system.

Figure 7, the RAFT CAS Display presents another example of the benefits of RAFT. The system can provide the aircraft with a Collision Avoidance System (CAS) aircraft display or an enhanced Traffic Alert CAS (T-CAS) display that works in the close encounter environment. The present aircraft CAS only works when the planes are widely separated, moving at constant velocity, and statistically have few or no collisions. This enhanced T-CAS display (that can be put aboard the aircraft) has the necessary data parameters to anticipate and prevent crashes. This figure shows two planes on a collision course. With the sharing of cooperative data, such as the velocity and Euler angle vector data that come from the INS and go to the DFDR and the aircraft's present T-CAS transponder data, all of the necessary data parameters to anticipate and prevent a collision exist. In the close encounter environment, differentiating the existing aircraft CAS radar or GPS position vectors to derive velocity is too noisy and time consuming for a reliable collision avoidance capability. Thus RAFT, by its cooperative sharing of data, provides a means toward the global prevention of many of the in-air collisions (e.g. Lockheed C141 Starlifter and German/Russian aircraft that collided over the southern coast of Africa on 9/13/97 killing 33; Boeing 747 and Ilyushin II-76TD collided over New Delhi, India killing 349). These fatalities can be avoided with RAFT CAS or a RAFT enhanced ATC or preferably both. Another advantage of the RAFT implementation is that it permits the CAS display in the flight deck and ATC to work both in the air and on the ground to prevent air, runway, and ground to air boundary incursions. It also will permit the ATC and aircraft to select and view, on demand, identical displays to prevent misunderstandings of intent.

Figure 7 also depicts a plane flying on a non-collision course that is experiencing two problems. One problem is that it only has one of its landing gears down and the other is that it only has fifteen minutes of flight time fuel remaining. These are depicted with a flashing landing gear and low fuel remaining icons that pulsate so as to increase the flight crew and controllers situation awareness of

the problems. The problem icons only come on when a problem exists so as not to increase operator work loads or unnecessarily clutter the displays during routine operations. In fact, like the warning icons in a car, these icons decrease work load by permitting the operator to concentrate on the main task and not so much on the inferences of the metered displays or misinterpretations of verbal communication.

Figure 8 depicts how RAFT provides an aircraft data super highway, similar to the Internet that respects an air carrier's privileged data. It shows air carriers having both privileged and safety related data. This data is transmitted to a global satellite communications link that provides two-way communications to the ground CGBS. Once the data is on the ground the data packets are sorted and distributed to the air carriers and ATC. Each air carrier receives its own data, including safety and privileged encrypted data. At their facility they can decipher their privileged data. The safety data on the other hand is cooperatively shared with the air traffic controller management systems and the air carriers. This will fill the present safety data vacuum by providing the sensor data necessary to prevent most information deficient accidents. It provides on a timely basis, via the Internet at essentially no cost, the FOQA data to the air carriers. RAFT substantially increases safety and increases air carrier operational efficiency. Once the data is at the air carriers the standard FOQA post-flight software tools can be utilized. In addition RAFT permits a paper-less inspection, maintenance log and Aircraft Safety Reporting System (ASRS). Thus, it corrects the deficiencies in the present flight recorders and provides a significant enhancement to air safety and operational efficiency by providing an aircraft data super highway. It unifies the communications approach so that relevant data parameters are globally visible and readily available to users.

Figure 9, Aircraft On-Board Layout, depicts the sharing of DFDR data with the ground system. It shows some of the most salient parameters being shared to greatly enhance air safety, security and efficiency. It also illustrates how RAFT will bring a much needed level of globally enhanced capability, redundancy and optimality to the existing system that is presently overly dependent on voice communication and inferences. The 1998 losses of ATC radar visibility of the President's plane over CONUS from the ATC/M system is still another reason for RAFT. It provides a satellite based ATC/M surveillance system that would be a redundant back up to the existing ground based radar ATC systems. In the low air traffic density areas that extend beyond the radar horizon or don't have radar coverage it would provide a non-redundant ATC/M global safety net function. RAFT, by its global coverage, can prevent many of the collisions that take place beyond ATC/M surveillance radar horizons. Thus RAFT provides significant enhancements to the present system that is prone to failures of omission, commission and misinterpretation as well as equipment outages.

Figure 10, shows a chronology of the communication costs per plane per average flight. The curve shows that the communication costs for a global system is being drastically reduced. This is a direct result of the technology advancements increasing the channels and bandwidth while reducing the cost of Low Earth Orbit (LEO) digital data communication satellites. By the year 2003 several low cost high band width LEO satellite communication systems will be operational and other low cost LEO satellite constellations will be in the process of getting to be globally fully operational. These LEO systems, projected to the year 2008 will bring down the average cost of the RAFT system to only nine dollars per flight. It is estimated that the safety benefit alone for RAFT at that time will represent a savings to the total of all air carriers of over \$400 million per year. When the other operational efficiency benefits of RAFT are factored in, the savings will reach over a billion dollars per year.

Table 1 is a tabulation of the worldwide air carrier fatalities and fatal accidents between 1987 and 1996. This table is a compilation of accidents sorted by causal type for all of the world's air carrier operators and by only the US operators. It tabulates the percent of fatalities and the percent of

fatal accidents by accident type for the present system and compares these actual statistics with an estimate of what they would be if an operational RAFT system were in place. It shows that the RAFT system is more effective for the US operators than for the worldwide operators. This is because world wide air carriers presently experience more sabotage and highjacking than the US air carriers. Even though RAFT is not very effective in preventing sabotage and high-jacking accidents, it can help through its video system by ensuring that the person checking in at the ticket counter is the same person that boards the plane. Other applications of the passenger compartment video is to monitor, record and hopefully discourage passengers from trying to enter the flight deck, seriously interfering with the function of the flight attendants, and endangering the aircraft. This is similar to the security video monitoring done in many businesses and government offices. A cargo area video sensor also serves as a backup fire and smoke detector as well as a detector of potentially dangerous cargo shifts. RAFT can reduce US fatal accidents by 78 percent.

3. CONCLUSIONS

RAFT is a world wide real-time remote aircraft flight recording telemetry system for enhanced air space capacity, passenger safety, security and operational efficiency. It utilizes existing state-of-the art communications, Internet, computer and software technology to unify the total avionics system. The DFDR sensor information, supplemented with video and radar data, is brought out of an archival database and into a real-time usable accident prevention system. In addition, it ends the information vacuum created by the aircraft and air traffic controller, where presently each acting independently, don't have the necessary measurement sensors that are required to prevent a crash. This information vacuum has compromised the safety net and is the major cause of the stagnant air carrier fatal accident rate. It has led to a situation where **currently air travel is over nine times more lethal than bus travel¹, and over three times more lethal than car travel. In addition it is now fifteen times more lethal to be a passenger on a commercial airliner than it is to be a passenger on the space shuttle.** The space shuttle utilizes a real time ground based global monitoring, recording, simulation and expert advisor system to make space flights safe. In this day and age, this proven safety technology can be harnessed and utilized for commercial air travel. This will drastically reduce the fatal accident rate as well as make air travel more economical.

By the cooperative combining of the aircraft and ground data sensors, and thus sharing the safety parameters in real time, the effective sensor suite is enhanced and the system can now anticipate many types of crashes. This crash anticipation capability provides the visibility and time necessary for the prevention of fatal accidents. Furthermore, by the global transmission of telemetry of the DFDR parameters to a ground processing and distribution station, it provides a best estimate of a downed aircraft position for timely search and rescue operations. It also minimizes and eventually can eliminate the need for the costly and time-intensive recovery of the flight recorder. RAFT unifies the air space communications information system. It provides an aircraft data super highway, similar to the Internet, to assure that the relevant data parameters are globally visible and readily available to the people who need them in order to timely and optimally solve problems in a cost-effective manner prior to them becoming accidents. Furthermore, it optimizes the safety net and adds a level of redundancy to the present and planned sub-optimal capacity and safety systems, which are prone to single thread failures. The system, which can be operational in five years, alleviates a broad spectrum of operational efficiency, air space capacity and air safety problems. RAFT provides the safety net that should be in place prior to any transition to free flight.

NOTES:

1. Recent DOT Statistics show that air travel is over nine times more lethal than bus travel:

★ US Air Carriers have 4.8 fatalities per 100 million miles traveled based on 5.9 billion vehicle miles.

★ US Buses have 0.5 fatalities per 100 million miles traveled based on 6.4 billion vehicle miles.

(Buses were taken for the comparison statistics with carrier aircraft since both are classified as multi-passenger transportation carrier vehicles and their annual vehicle miles are equivalent.)

The recent statistics also show that air travel is over three times more lethal than bus travel and fifteen times more lethal than travel on the space shuttle.

The air carrier fatal accident rate has remained essentially constant over the last twenty years. This constant fatal accident rate is in spite of the advances in:

Pilot training due to the use of high fidelity flight simulators.

Aircraft materials due to enhanced fabrication methodology and superior metallurgy that has made them stronger and less subject to fatigue.

Avionics enhancements due to large scale integrated (LSI) semi-conductors that made the electronics smaller and more reliable, and improvements in engines and fuel that have made them more reliable.

Engine reliability due to advancements in engine fabrication and materials, computer aided design (CAD) and simulations.

In the years between 1965 and 1970 there was a significant reduction in the fatal accident rate and fatalities. This was due largely to improvements in jet engines that made them more reliable, microwaves that provided enhanced surveillance radar ATC/M and Instrument Landing Systems (ILS), and inertial navigation systems (INS) that reduced the aircraft's dead reckoning position errors. The radar based ATC also significantly enhanced the automated sharing of safety data between the plane and the ground monitoring system. Since the 1970's, there has not been a significant increase in the number of safety parameters that are automatically shared between the flight deck and the ATC. It has been this stagnation in avionics information that has directly caused the two decades of stagnation in the air carrier fatal accident rate. RAFT, which can be operational in five years, ends this information vacuum and thus reduces the fatal accident rate while making air travel more economical.

BIOGRAPHY: SY LEVINE

For the past several years Sy has been working on a world wide, real time, remote monitoring system called RAFT that will enhance air transportation safety, security, operational efficiency and air space capacity. Prior to this endeavor he was the Chief Engineer at the Northrop Grumman Corporation Electronic Systems Division in Hawthorne, California. One of his early patents, that dramatically changed commercial aircraft navigation, was for the first commercial inertial navigation system, INS, put aboard Pan American aircraft. He is an internationally recognized expert in program management, systems, navigation and servomechanisms.

1 FIGURE 1

AVIONICS SYSTEM

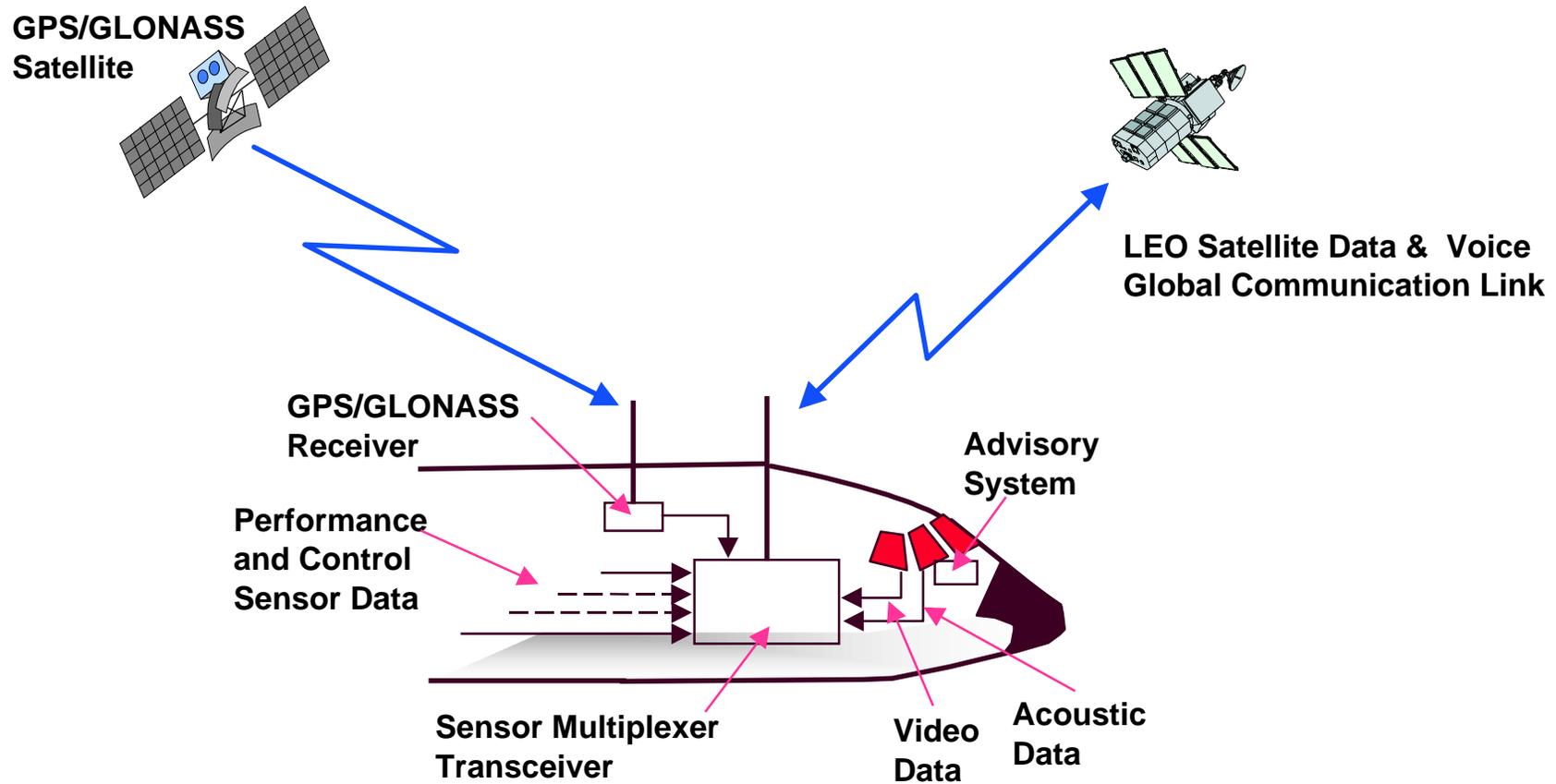
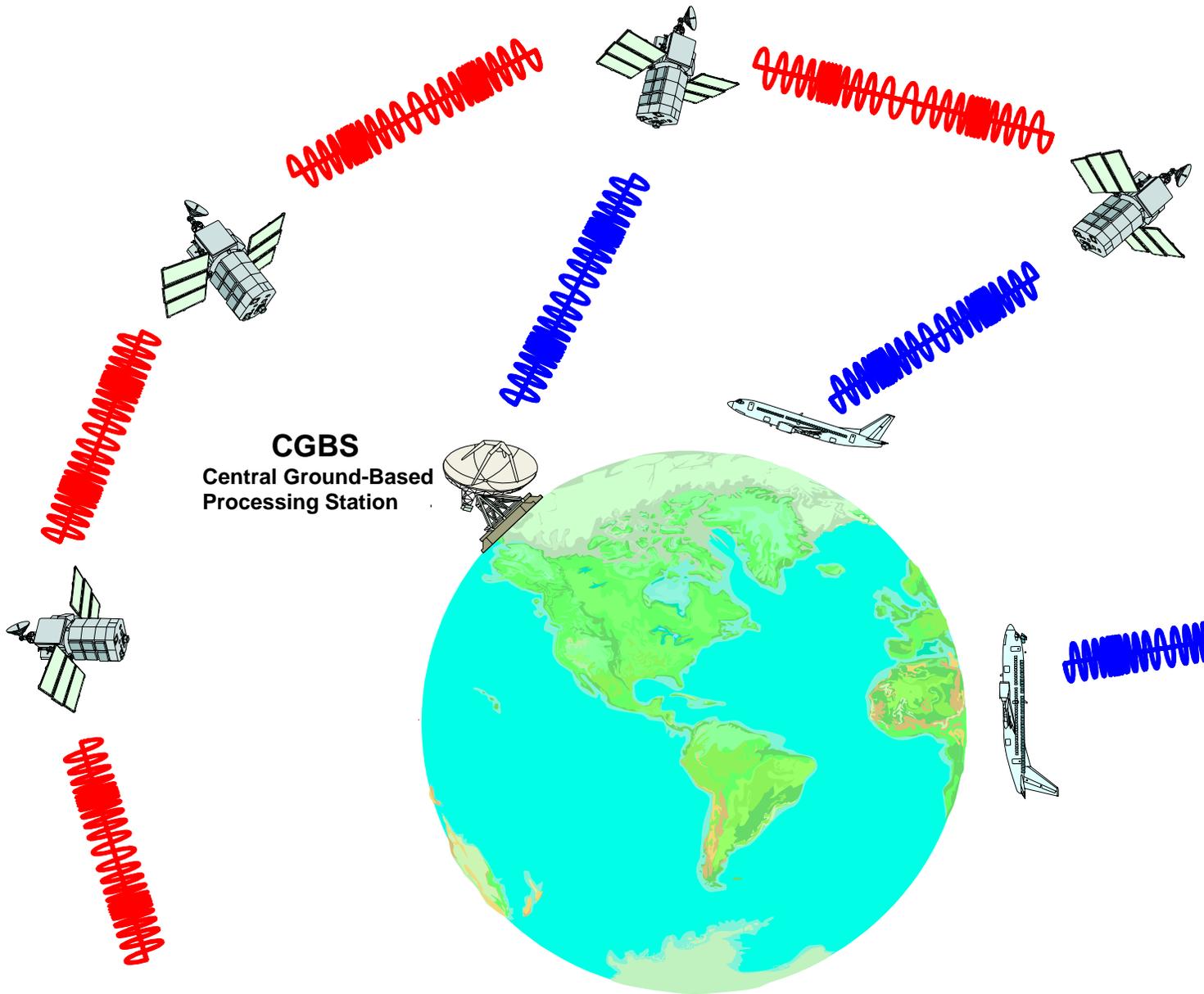


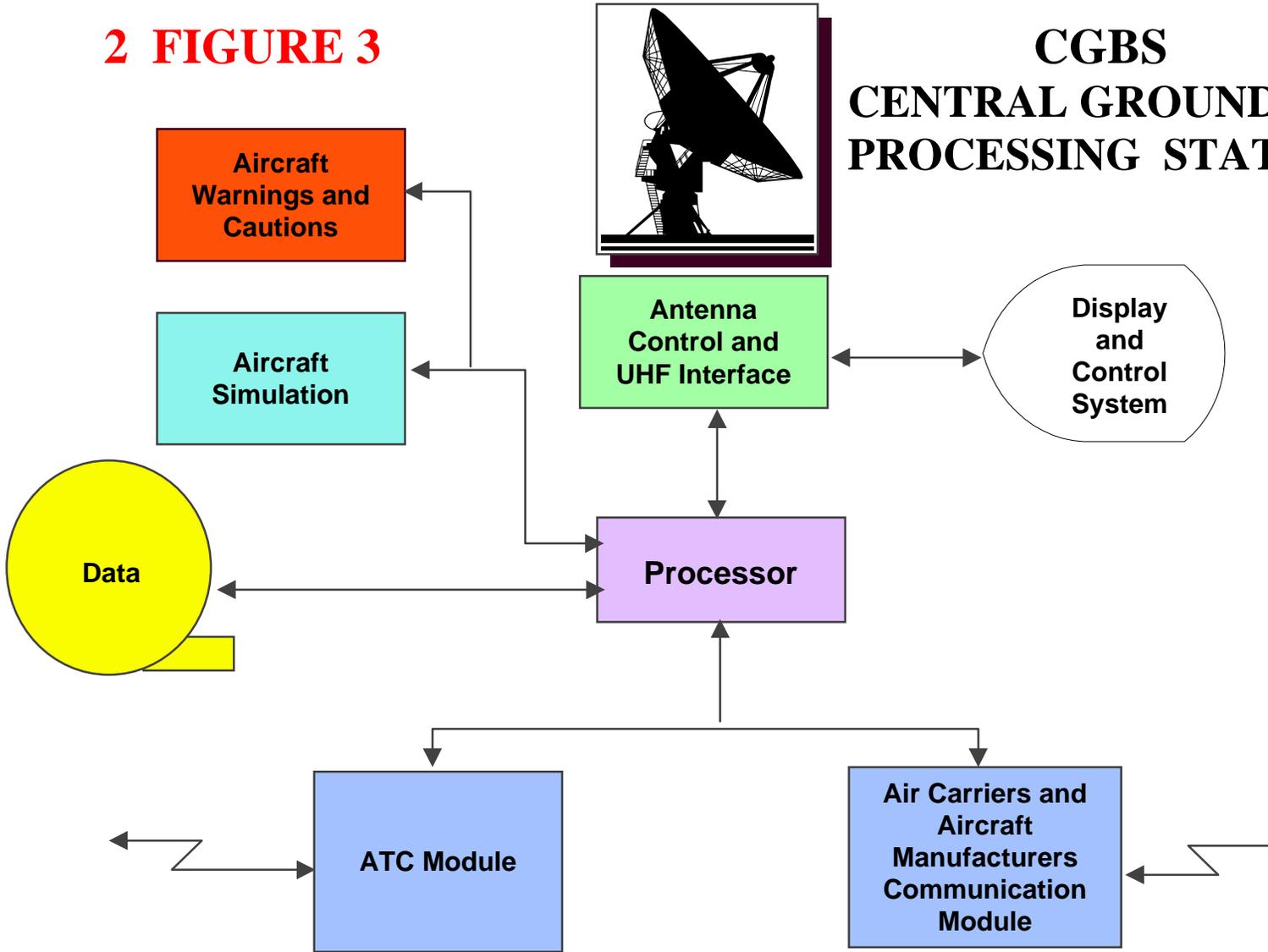
FIGURE 2

**LEO SATELLITE DATA
GLOBAL COMMUNICATIONS**



2 FIGURE 3

**CGBS
CENTRAL GROUND
PROCESSING STATION**



3 FIGURE 4

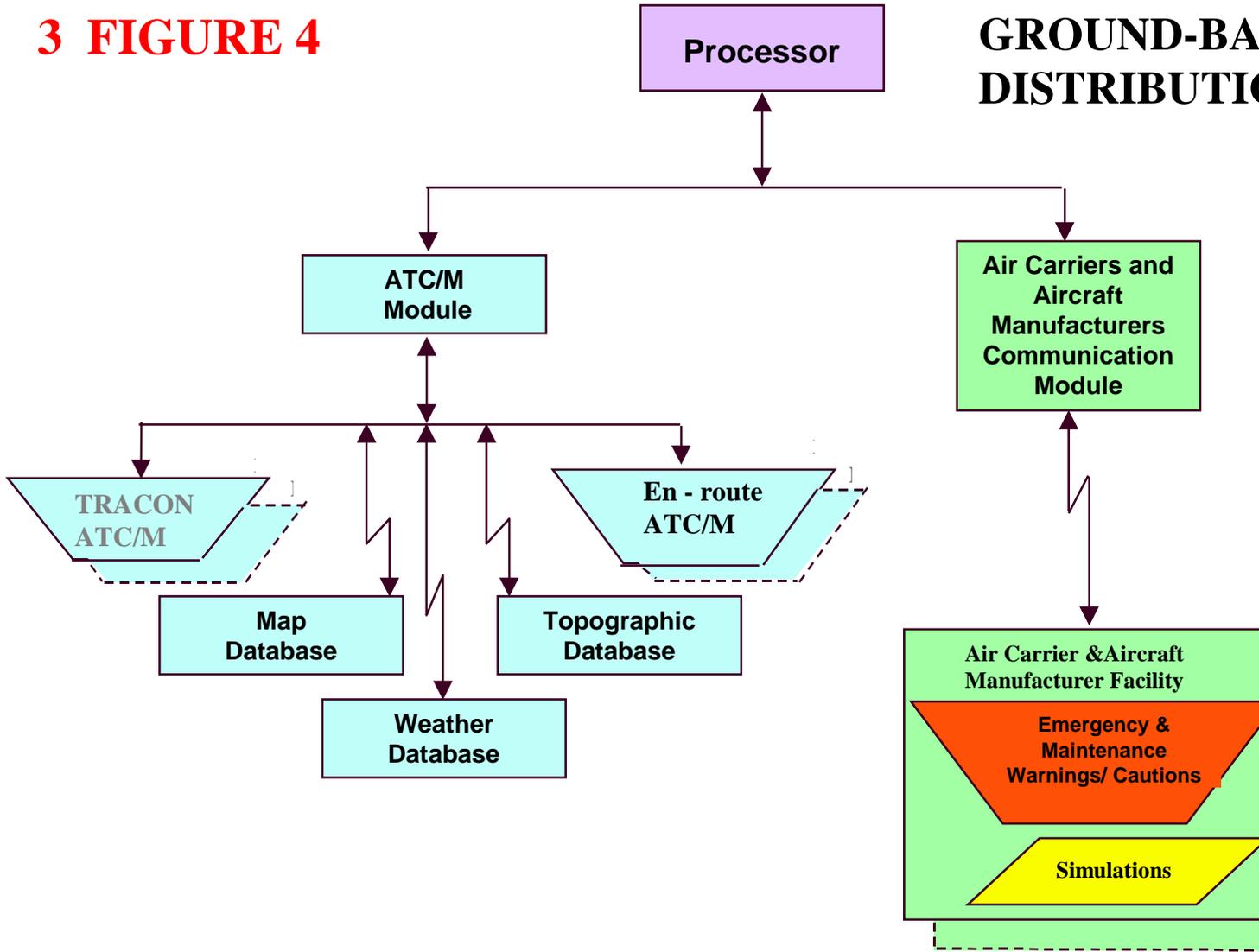
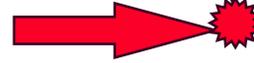
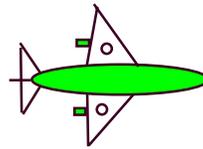
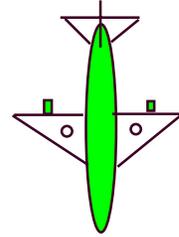


FIGURE 5

TENERIFE ET AL.

RAFT PROVIDES AUTOMATED COLLISION AVOIDANCE ALERTS ATC/M & CAS ENHANCED CAPABILITY DISPLAY

<u>TRANSLATOR</u>		
	<u>DOWN</u>	<u>UP</u>
LANDING GEAR	○	--
LANDING GEAR DOWN- BRAKE ON		●



Note: The 583 crash was head-on
is a generic representation
shows aircraft on
runway crossing

<u>AIRCRAFT</u>	<u>COLOR CODE TRANSLATOR</u>		
	<u>GREEN</u>	<u>RED</u>	<u>YELLOW</u>
FUSELAGE	PLANE MOVING	STOPPED	-----
ENGINE	HIGH THRUST	OFF	LOW
BRAKE	ON	-----	-----

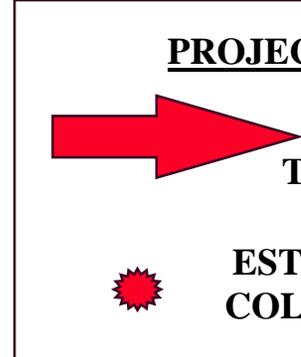
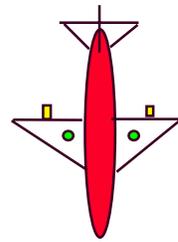
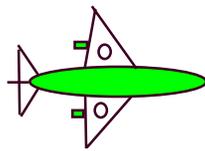


FIGURE 6 TENERIFE, ET AL., NO MORE RAFT PROVIDES A SAFE TRAJECTORY DIS ATC/M & CAS ENHANCED CAPABILITY

<u>TRANSLATOR</u>		
	<u>DOWN</u>	<u>UP</u>
LANDING GEAR	○ --	
LANDING GEAR	●	--
BRAKE ON		--



Note: The 583 crash was head-on. This is a generic representation showing aircraft runway crossing.



<u>COLOR CODE TRANSLATOR</u>			
<u>AIRCRAFT</u>	<u>GREEN</u>	<u>RED</u>	<u>YELLOW</u>
FUSELAGE	PLANE MOVING	STOPPED	-----
ENGINE THRUST	HIGH	OFF	LOW
BRAKE	ON	-----	-----

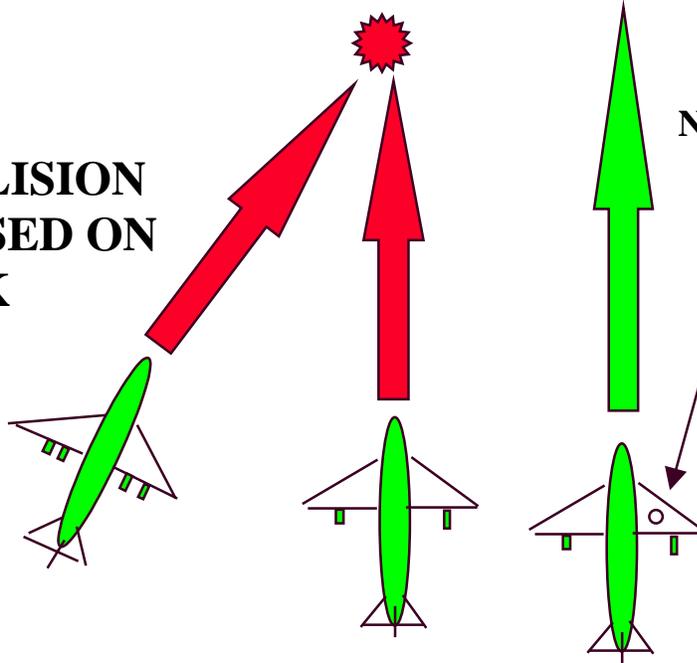
PRO
SAFE TR

FIGURE 7

RAFT CAS DISPLAY

**PROJECTED COLLISION
TRAJECTORY BASED ON
AIRCRAFT TRACK
VECTORS**

- VELOCITIES (V_n, V_e, V_h)
- PRESENT POSITIONS
- PROJECTED POSITIONS



NOTE: ONLY ONE LANDING GEAR IS DOWN

FLASHING PROBLEM
LANDING
15 MINUTES REMAINING



<u>TRANSLATOR</u>		
	<u>DOWN</u>	<u>UP</u>
LANDING GEAR	○	--

PROJECTED COLLISION

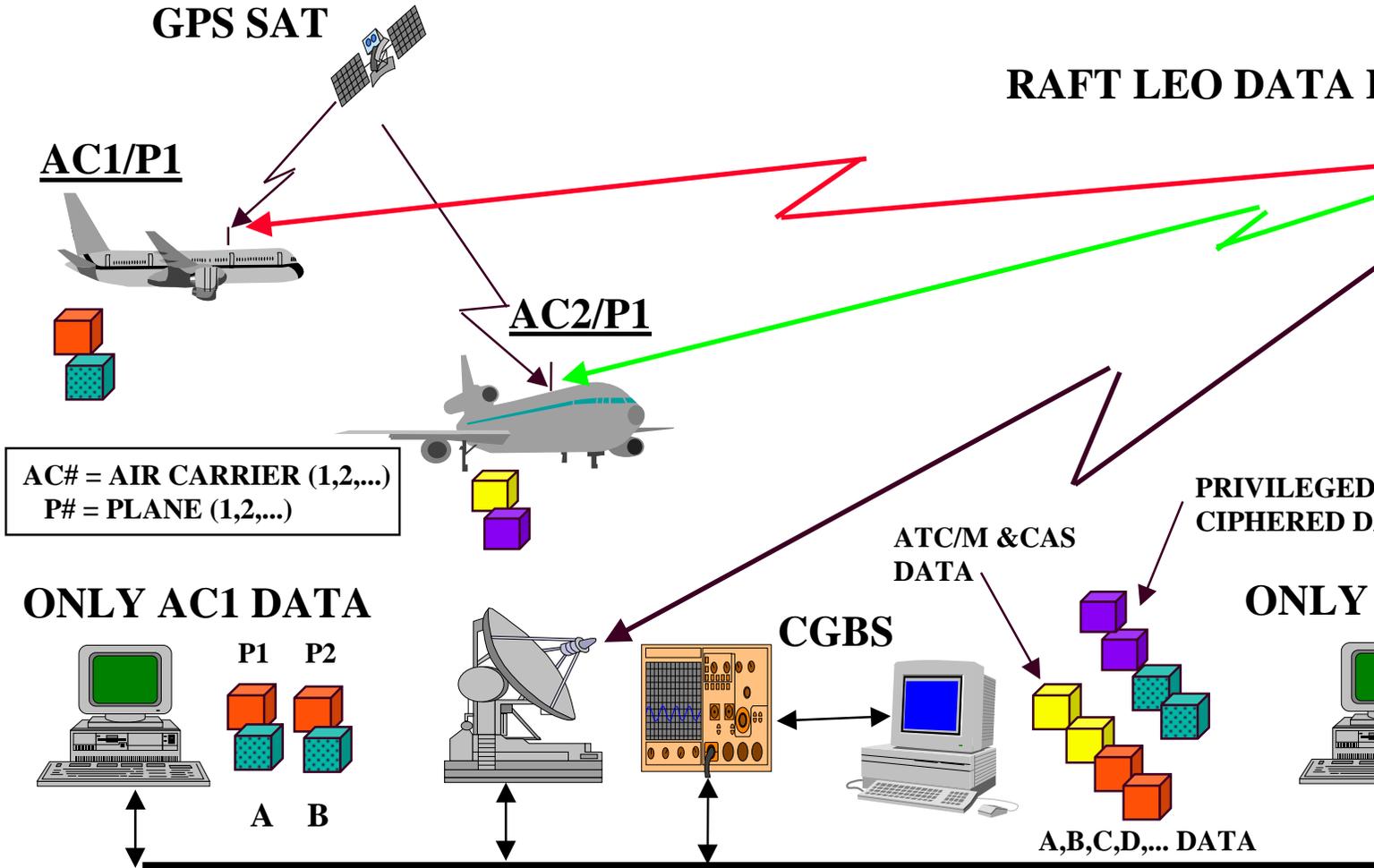
TRAJECTORY

→ SA
→ CO

★ ESTIMATED COLLISION

FIGURE 8

**RAFT PROVIDES AN AIRCRAFT DATA SUPERHIGHWAY
(SIMILAR TO THE INTERNET)
THAT RESPECTS AN AIR CARRIER'S PRIVACY**



4 FIGURE 9

RAFT Aircraft On- Board Lay-out

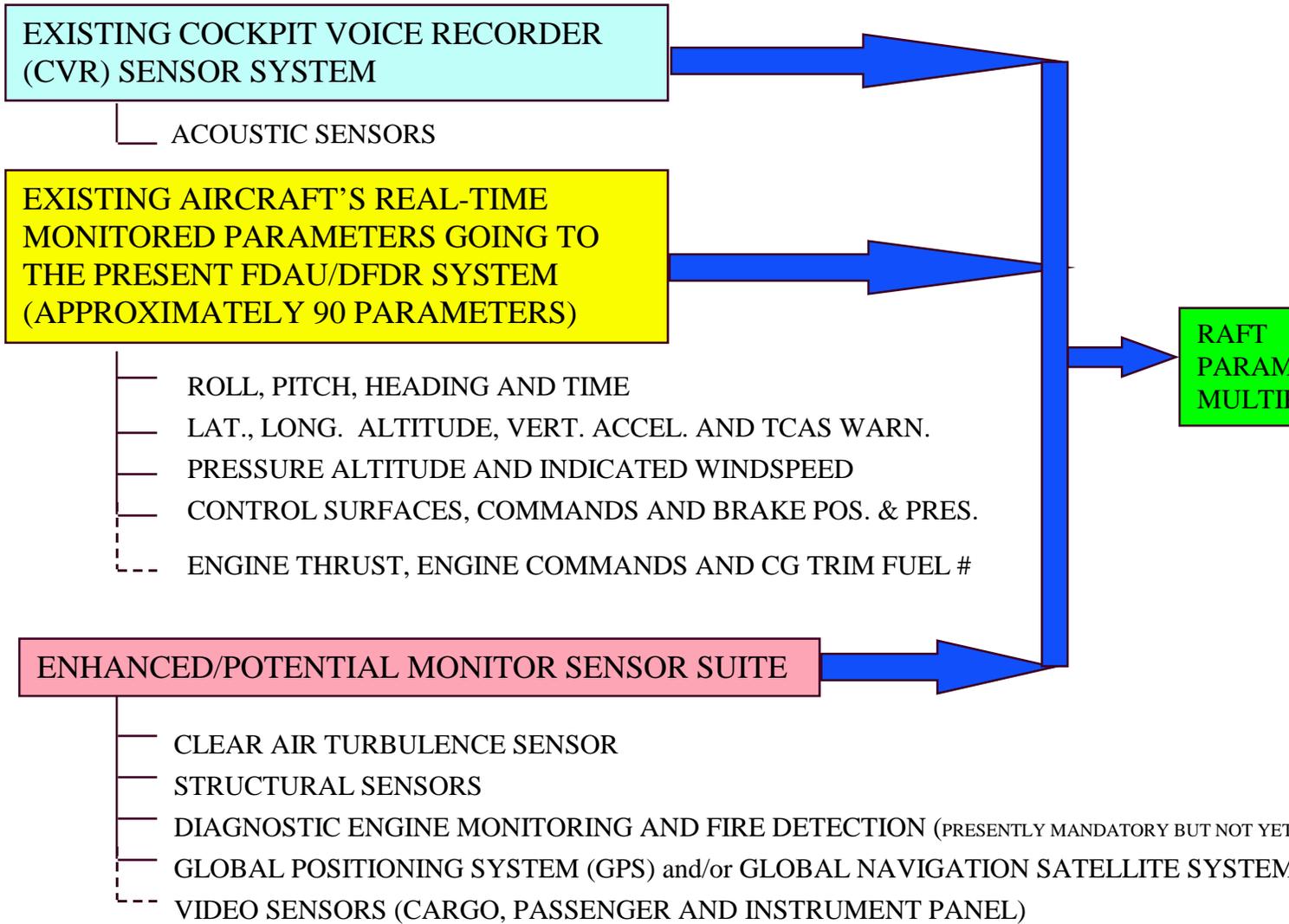


FIGURE 9 (CONTINUED) RAFT Aircraft On- Board Lay

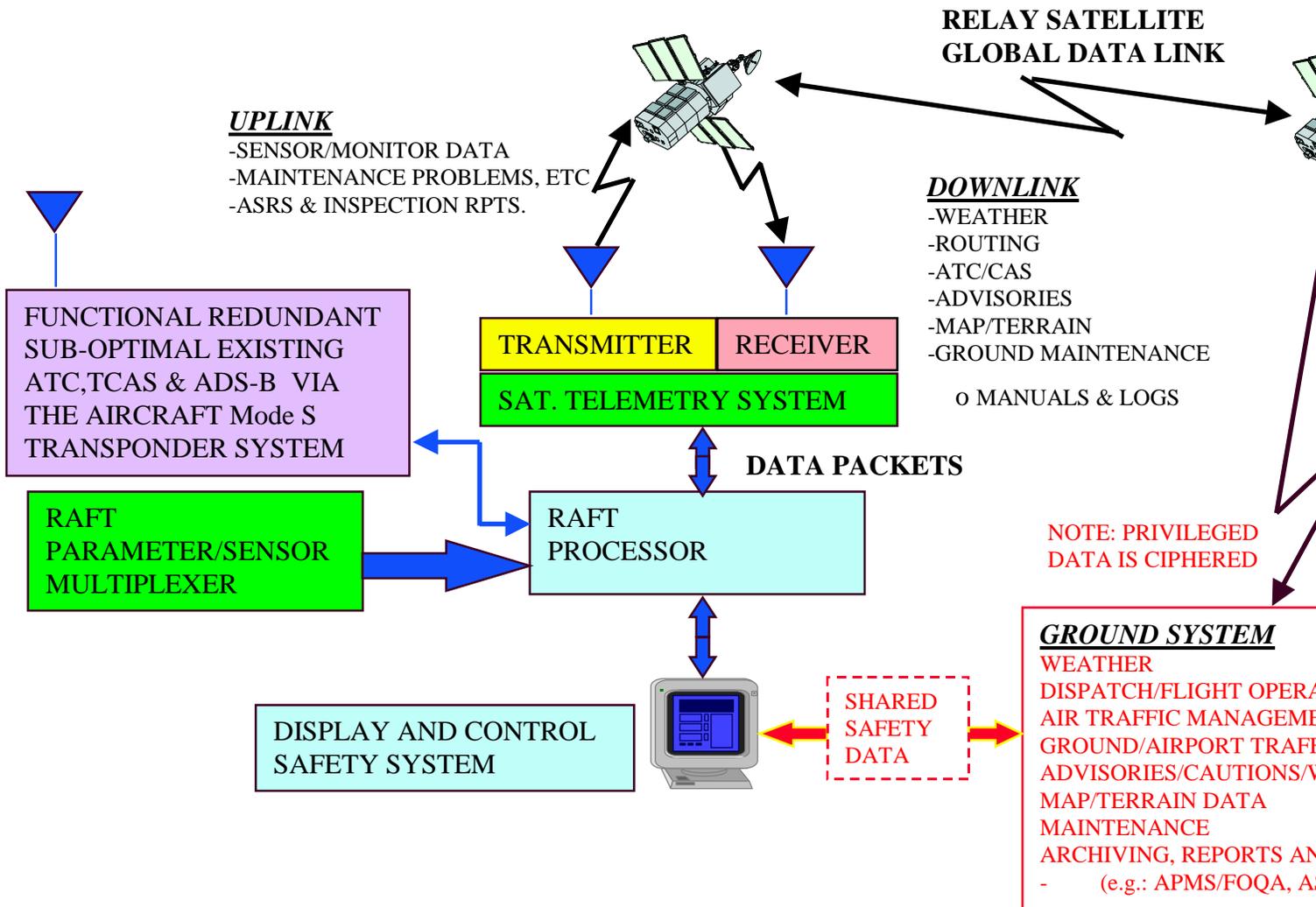


FIGURE 10

CHRONOLOGY OF SATELLITE PER FLIGHT COMMUNICATIO

AVERAGE \$ COST PER PLANE PER AVERAGE FLIGHT
(AVG. FLT. TIME = 90 MIN.)

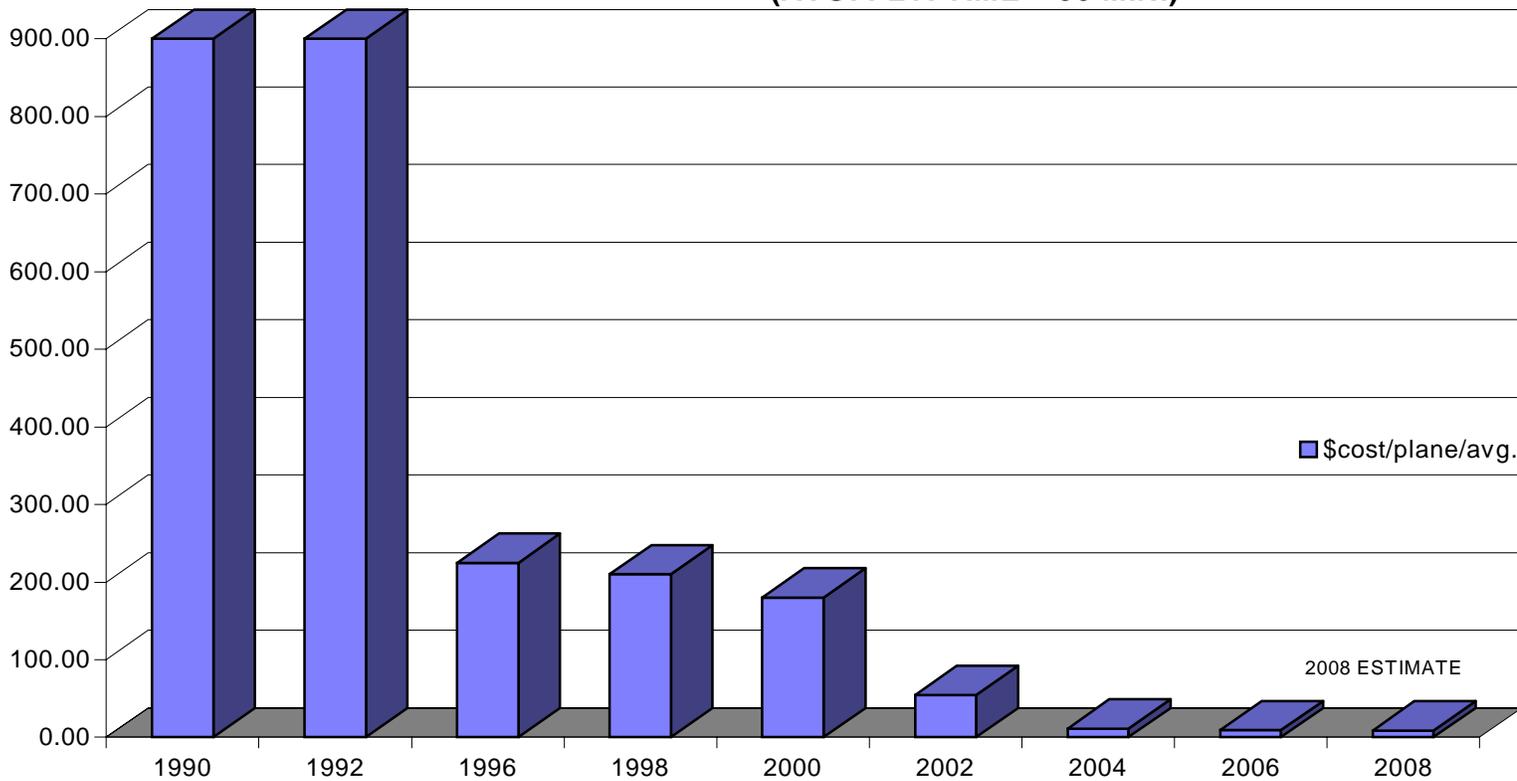


TABLE 1**WORLDWIDE AIR CARRIER FATALITIES AND FATAL ACCIDENTS
FOR THE YEARS 1987 THROUGH 1996**

	<u>Total</u>	<u>Total</u>	<u>US Operators</u>	<u>US Operators</u>	<u>RAFT</u>	<u>RAFT</u>
<u>FATAL ACCIDENT TYPE/QTY</u>	<u>Fatalities</u>	<u>%Fatalities</u>	<u>Fatalities</u>	<u>%Fatalities</u>	<u>Fatalities</u>	<u>%Fatalities</u>
Controlled Flight Into Terrain (CFIT)	2396	32.01%	312	19.68%	479	17.04%
- CFIT Only On Approach	957	12.79%		0.00%	191	6.81%
Loss of Control In Flight	2228	29.77%	482	30.41%	1114	39.62%
In Flight Fire	760	10.15%	340	21.45%	152	5.41%
Sabatage	607	8.11%	254	16.03%	546	19.43%
Mid-air Collision	506	6.76%	0	0.00%	101	3.60%
Hijack	306	4.09%	38	2.40%	275	9.79%
Ice and/or Snow	162	2.16%	57	3.60%	32	1.15%
Landing	128	1.71%	3	0.19%	26	0.91%
Windshear	119	1.59%	37	2.33%	36	1.27%
Fuel Exhaustion	113	1.51%	0	0.00%	23	0.80%
Other Unknown	111	1.48%	17	1.07%	22	0.79%
Runway Incursion	45	0.60%	45	2.84%	5	0.16%
Rejected Take Off (RTO)	3	0.04%	0	0.00%	1	0.02%
TOTAL FATALITIES	7484	100%	1585	100%	2812	100%
% REDUCTION IN FATALITIES					62%	
	<u>Fatal</u>	<u>% Fatal</u>	<u>US Fatal</u>	<u>US % Fatal</u>	<u>RAFT</u>	<u>RAFT</u>
<u>FATAL ACCIDENT TYPE/QTY</u>	<u>Accidents</u>	<u>Accidents</u>	<u>Accidents</u>	<u>Accidents</u>	<u>Accidents</u>	<u>Accidents</u>
Controlled Flight Into Terrain (CFIT)	36	26.47%	4	11.76%	7	15.32%
Loss of Control In Flight	38	27.94%	11	32.35%	19	40.43%
In Flight Fire	4	2.94%	2	5.88%	1	1.70%
Sabatage	5	3.68%	1	2.94%	5	9.57%
Mid-air Collision	2	1.47%	0	0.00%	0	0.00%
Hijack	8	5.88%	1	2.94%	7	15.32%
Ice and/or Snow	5	3.68%	3	8.82%	1	2.13%
Landing	9	6.62%	1	2.94%	2	3.83%
Windshear	3	2.21%	1	2.94%	1	1.91%
Fuel Exhaustion	7	5.15%	0	0.00%	1	2.98%
Other Unknown	14	10.29%	6	17.65%	3	5.96%
Runway Incursion	4	2.94%	4	11.76%	0	0.00%
Rejected Take Off (RTO)	1	0.74%	0	0.00%	0	0.00%
TOTAL FATALITIES	136	100%	34	100%	47	100%
% REDUCTION FATAL ACCIDENTS					65%	

