2003-09

Secure ground-based remote recording and archiving of aircraft "Black Box" data

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https://hdl.handle.net/10945/6275

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

SECURE GROUND-BASED REMOTE RECORDING AND ARCHIVING OF AIRCRAFT "BLACK BOX" DATA

by

Paul R. Schoberg

September 2003

Co-Advisors: Cynthia E. Irvine
Scott Cote

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2003	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: Secure Ground-Based Remote Recording And Archiving Of Aircraft "Black Box" Data.	**5. FUNDING NUMBERS**
6. AUTHOR(S) Mr. Paul R. Schoberg	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) Federal Aviation Administration 800 Independence Avenue SW, Washington DC 20591	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	**12b. DISTRIBUTION CODE**

13. ABSTRACT *(maximum 200 words)*

Aircraft accident investigation centers upon the analysis of all available information about the accident flight in the period leading up to the final catastrophe. Key among the sources of information is data captured and recorded in the flight data recorder and cockpit voice recorder, which are often referred to as the aircraft "black boxes". For some accidents, this flight data may be lost entirely or partially damaged and largely unusable. The aircraft flight data recorders are the only place where flight data is recorded. This single recording point is a vulnerability to the availability of flight data that can be addressed by creating another place where the data is stored.

This thesis examines the feasibility of and discusses the technical framework necessary for a system that transmits flight data from an aircraft to a ground recording station. The focus will be upon the requirements for security and assurance of the information flow, so that the confidentiality, integrity, availability and authenticity of the data are ensured.

14. SUBJECT TERMS Flight Data Recorder, FDR, Cockpit Voice Recorder, CVR, Secure Transmission, Secure Storage, Ground Capture, Flight Data	**15. NUMBER OF PAGES** 194
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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SECURE GROUND-BASED REMOTE RECORDING AND ARCHIVING OF AIRCRAFT "BLACK BOX" DATA.

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

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ABSTRACT

Aircraft accident investigation centers upon the analysis of all available information about the accident flight in the period leading up to the final catastrophe. Key among the sources of information is data captured and recorded in the flight data recorder and cockpit voice recorder, which are often referred to as the aircraft "black boxes". For some accidents, this flight data may be lost entirely or partially damaged and largely unusable. The aircraft flight data recorders are the only place where flight data is recorded. This single recording point is a vulnerability to the availability of flight data that can be addressed by creating another place where the data is stored.

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ACKNOWLEDGMENTS

The preparation of this thesis would not have been possible without the technical assistance of the following great people (in alphabetical order):

- **Mr. Scott Coté**
  Computer Science Department
  Naval Postgraduate School
  Monterey, California USA

- **Ms. Tracey Donohoe**
  Flight Dispatch
  Qantas Airlines
  Sydney, NSW Australia

- **Mr. Frank Doran**
  Senior Engineer
  L3 Communications
  Sarasota, Florida USA

- **Mr. J. D. Fulp**
  Computer Science Department
  Naval Postgraduate School
  Monterey, California USA

- **Mr. James Treacy**
  Federal Aviation Administration
  Renton, Washington USA

- **Mr. Timothy Ridgely**
  Senior Engineer
  Boeing Aircraft Company
  Everett, Washington USA

I wish to thank the companies and agencies involved for allowing me the time to speak with their employees. Their ideas, thoughts and expertise greatly assisted me in this thesis effort.

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I. INTRODUCTION

A. THESIS STATEMENT

The purpose of this thesis is to ask and answer the following questions.

- Is it feasible to build a system that has the capability of transmitting flight data in real-time from commercial and military aircraft to a ground recording station?
- What are the technical characteristics of such a system?
- What are the information assurance characteristics of such a system?

B. THESIS BACKGROUND

Disasters occur in aviation despite the best efforts of the aviation community to prevent them. Determining the cause of the accident from burning wreckage, or in the absence of wreckage, is essential. By studying the causes of past accidents we can affect changes to present procedures, practices and manufacturing methods in the hopes of making the business of air transportation safer and more reliable.

Presently, the primary method of collecting flight data concerning the technical state of the aircraft before and during the accident sequence is to use the so-called aircraft "black boxes" (Flight Data Recorder [FDR] and Cockpit Voice Recorder [CVR]), which are devices aboard the aircraft that record various flight parameters and audio signals and are designed to survive the crash. But, they do not always survive the crash or are not always locatable. It is relatively common that some or all data contained in recovered flight recorders is too damaged to be useful. When this occurs, valuable data is lost and the cause of the accident may never be known.

To allow the greatest possibility of having flight data available to post-crash investigators, it is proposed that the data presently recorded only by the on-board flight recorders also be transmitted off the aircraft and recorded at a location on the ground. This should be in addition to, and as a backup system for, the present system of FDR and CVR devices.

The technical problem of transmitting flight data from all of the aircraft wishing to do so to the ground involves the following key components:

- A method of collecting the data that is to be transmitted off the aircraft
- A method of formatting flight data for transmission
- A method of radio transmission of the data
- A communications network capable of handling transmissions originating from all aircraft seeking to transmit such data at any point in time
- A data link network capable of sending the flight data received by the communications network to a ground collection and recording station
- A ground station capable of capturing and storing the flight data

All of these system components require security measures to ensure the data arrives at the ground recording station and is known to be genuine and not compromised in any way.

C. THESIS SCOPE

This thesis is a FL500[1] view of the design of a system having the capability of remote, ground-based recording of flight data. The proposed system is called the Real-Time Flight Data Transmission System.

[1] FL means "Flight Level". Each FL is approximately equal to 100 vertical feet, making FL500 approximately equal to 50,000 feet.

The major components of this thesis are:

- Introduction
- Present State Of Flight Data Capture And Recording
- Transmission Of Flight Data Off Aircraft
- Data Network
- Ground Capture And Storage
- Practical Aviation Concerns
- Summary, Conclusions and Future Research

D. AUTHOR'S BACKGROUND / THESIS DESIGN

The author holds three FAA airman certificates:

- Airline Transport Pilot (ATP) certificate with ratings for Single-engine and Multiengine (Land)
- Certified Flight Instructor (CFI) certificate with ratings for Single- and Multiengine (MEI) and Instrument—Airplane (CFII)
- Flight Dispatcher certificate

Much of the aviation information presented is drawn from the author's professional activities within the aviation industry, which includes being a corporate pilot and flight instructor for a major airline.

This thesis attempts to bridge between aviation and computer science. To accomplish this goal, it is necessary to present information on "both sides of the fence".

The thesis attempts to present relevant information to both disciplines, so that each understands the concerns of the other as relates to the Real-Time Flight Data Transmission System.

E. BACKGROUND INFORMATION

This section presents general background information about flight data recording. Specific information is presented in subsequent chapters.

1. Why Record Flight Data?

Flight data is recorded to enhance flight safety. The goal is to save lives and reduce property damage.

The availability of the data contained in the flight recorders is vital to crash investigators as they attempt to determine the cause of an aircraft accident. If we understand the cause of a disaster, then we can apply this knowledge in the creation of safer regulations, safer procedures, better training, better engineering and better manufacturing techniques.

2. What Is A Flight Recorder (A.K.A. "Black Box")?

A flight recorder is an electronic device placed aboard an aircraft. It receives information from sensors located around the aircraft that measure the technical state of the aircraft, records this information, and is designed to survive the tremendous forces experienced during and after an air crash — maybe the only thing that survives the crash — so investigators may use the information to help analyze the cause of the crash.

A flight recorder, commonly known as a "black box", is actually painted orange. This is to facilitate location of the recorder among the crash debris field.

3. A Brief History Of Flight Data Recorders

While flying today is very safe, in the past many terrible air crashes have claimed thousands of lives. What went wrong? In part, the safety of flight comes from knowing the answer to this question. Beginning in the 1940's, we have been concerned with knowing all we can about what went on aboard the accident aircraft by placing a crash-hardened recording device on board.

But, the forces experienced by a crashing aircraft are extreme. Technology had to be invented to create a device that could withstand these extreme forces. As a result, the earlier flight recorders had a rather high rate of failure.

The first generation of flight data recorders used a process of embossing information on metal foil. The metal foil media could only be used once. Although the foil recording was very robust and it survived crashes fairly well, the boxes in which the recorders were contained did not sufficiently protect them. Loss of data was common as was failure of the recorder mechanism.

Metal foil is not capable of storing a large quantity of data. Early recorders placed only five flight parameters (such as airspeed, altitude and heading) on the foil. This limited amount of information is helpful when investigating the accident, but it is often insufficient and does not provide enough clues to answer investigator's questions.

The second generation of flight data recorders used magnetic tape. In the mid-1960's, hardening technology had advanced far enough to allow these fragile devices with vulnerable media to be used. In addition to recording many more flight parameters than the original five, magnetic tape also allowed recording of sound. The cockpit voice recorder became a mandatory piece of equipment on all commercial aircraft. Regulations required that the last thirty minutes of cockpit voice communications be recorded.

The third generation of flight data recorders are solid-state devices. They are capable of recording many more parameters than magnetic tape devices and do it in a digital format, which is more precise and reliable. The recording devices often have no moving parts, which makes them more resistant to the extreme forces experienced during the accident sequence [Source: L02].

4. Who Uses Flight Data And For What Purpose?

The primary consumer of recorded flight data is the National Transportation Safety Board (NTSB). The NTSB investigates air crashes, produces extensive reports of many factors concerning the accident, and makes safety recommendations to the FAA as a result of the findings of the investigation.

A secondary use of recorded flight data is to diagnose aircraft performance and systems. Although this usually does not come from the flight data recorders used for accident investigation, it often does use the same sensor network that is used to gather information for the flight data recorders.

It is important to note that data stored in the recorders is not used for certificate enforcement action against flight crews, nor is the raw data usually releasable to the general public. The NTSB may release transcripts of cockpit communications or findings as a result of flight data analysis, but does not release the actual raw data. Data concerning crashes that occur outside the United States may not be as tightly controlled as data concerning crashes that occur within the United States.

5. Who Records Flight Data?

The operators of certain aircraft are required to use flight data recorders. Operators of other aircraft may or may not be required to use them. The distinction involves the type of operation being conducted, including whether it is civilian or military.

a) Civilian Use Of Flight Recorders

The three most common types of operations are:

- 14 CFR Part 121 operations: Airlines
- 14 CFR Part 135 operations: Air Charter
- 14 CFR Part 91 operations: General Aviation

Part 121 operators are required to use flight data recorders for all flights. Part 135 and Part 91 operators are required to use flight data recorders if they operate large, transport category aircraft. Otherwise, for smaller aircraft, they are not required to use flight data recorders.

b) Military Use Of Flight Recorders

The military is interested in safety of flight and operates a fleet of aircraft carrying passengers. However, for tactical and "mission" operations, the military does not always require the use of flight recorders.

When military operations use flight recorders, the technical issues presented in this thesis also apply to those situations.

6. What Is Flight Data?

Items of interest to crash investigators consist of these broad categories of information:

- Flight performance
- Engine performance
- Control surface situation
- Aircraft systems status
- Environmental data
- Sounds
- Air-to-ground communications

There is no particular maximum amount of information the flight recorders can capture other than the number of items the particular recorder in use can handle, but there are minimum specifications.

The required data items that must be recorded are found in FAR 121.343 "Flight Recorders", and FAR 121.344 "Digital Flight Recorders for Transport Category Airplanes". See section II.E of this thesis for a listing of regulatory requirements for specific data items required by the FAA [Source: F02].

7. What Types Of Recorders Are There?

There are two flight recorders in use today, the Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR).

The FDR records flight situation data and information about the aircraft. Please see sections II.C and II.E for specific data items that are recorded.

The CVR records cockpit voice data. Please see section II.B for more information.

a) Flight Data Recorder (FDR)

Figure 1 shows a digital flight data recorder (DFDR) manufactured by L3 Communications [From Source: L01].

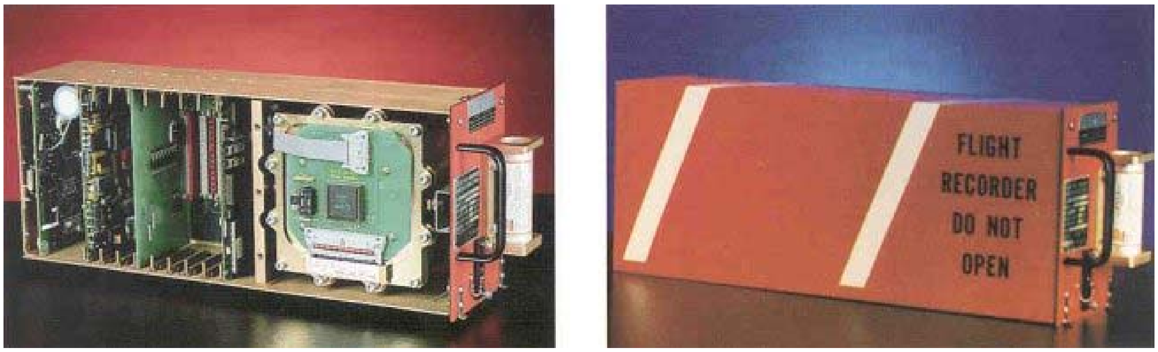

Figure 1. Flight Data Recorder

b) Cockpit Voice Recorder (CVR)

Figure 2 shows a cutaway view of a cockpit voice recorder manufactured by L3 Communications [From Source: L01].

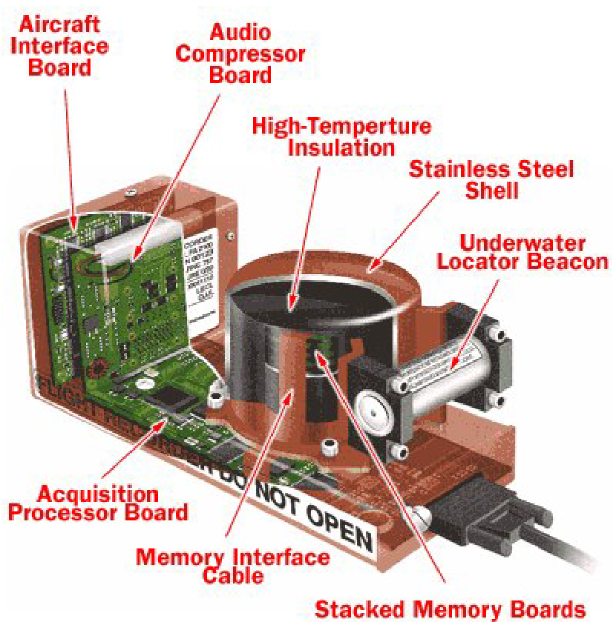

Figure 2. Cutaway Of Cockpit Voice Recorder

8. Where Are Flight Data Recorders Located?

The recorders are placed near the rear of the aircraft. This section of the airframe experiences the least violent conditions during the crash sequence. Therefore, recorders have the best chance of survival when placed at the rear of the aircraft.

Figure 3 shows typical placement of flight recorders and sensors around the aircraft [From Source: S01].

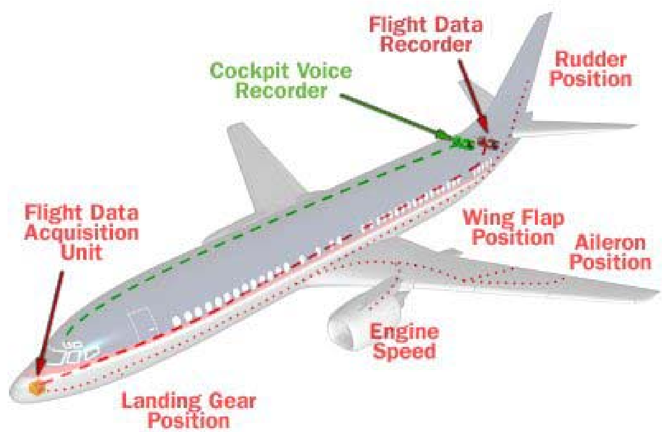

Figure 3. Location Of Flight Recorders

9. How Does A Recorder Get Its Data?

Sensors are placed around the aircraft wherever there is interesting data to be measured (see section II.E for a list of the types of data that is measured.) Sensors feed their data through wires or some kind of data network to the recorders located at the rear of the aircraft.

10. During What Phases Of Flight Is Data Recorded?

The recorders are turned on as part of the start-up procedure. They run continuously throughout all phases of the flight: start up, taxi, take off, climb, cruise, descent, approach, landing, taxi and shut down.

11. When Is Flight Data Used?

It would be nice to say flight data contained in the recorders is never used, but sadly that is not true. The data is accessed only after an aircraft accident or incident in which there is substantial damage to the aircraft, or those involving death or serious injury. NTSB regulation 830 formally defines these situations. FAR 121.343(i) requires that flight recorder information be saved if a flight terminates due to the reasons stated in NTSB 830.

NTSB accident investigators use recorded flight data in the course of the accident investigation as they attempt to determine the cause of the accident or incident.

Recorded flight data is not required to be made available in other circumstances, such as hijackings and so on, although certainly the contents of the flight recorders would be examined when a hijacked aircraft is recovered.

Recorded flight data is not used for investigation of certificate enforcement action directed against the flight crew.

12. Crash Survivability Of Flight Recorders

The FDR and CVR are designed to survive an air crash *enough* to allow investigators to access the data they contain. Please see section II.G for flight recorder crash survival specifications.

Figures 4 through 7 show images of recovered flight recorders [All Figures From Source: N05].

Figure 4. EgyptAir 990 Flight Data Recorder (View 1)

Figure 5. EgyptAir 990 Flight Data Recorder (View 2)

Figure 6. EgyptAir 990 Cockpit Voice Recorder

Figure 7. Alaska Airlines Flight 261 Flight Data Recorder

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II. FLIGHT DATA CAPTURE AND RECORDING

A. INTRODUCTION

This section discusses the present state of flight data capture and recording. Discussed will be the various sources of audio and voice information available during flight, the various sources of flight data, recorder crash standards, the regulatory environment, a brief background on recorder manufacturers, a description of the data networks on board aircraft and an assessment of the present security threat.

The present state of flight data capture and recording must be understood because it forms the basis for moving forward. Any new technology that is introduced, such as a system capable of transmitting real-time flight data to a ground recording station, will extend the state-of-the-art for collection of information made available to crash investigators.

As new technology is developed to extend the art of air crash investigation, the questions are *who will do it*, *what will be done*, *where do the changes need to be made*, *when should it be completed* and perhaps most important *a clear understanding of why we should do it*. It is therefore important to understand what is currently done in order to put a remote recording system in proper context.

B. AUDIO SOURCES

This section discusses the various sources of voice information that are available for recording during a flight.

The cockpit voice recorder (CVR) is the flight recorder used to capture audio information. Perhaps "cockpit voice recorder" is a misnomer. Although most of it does, not all voice information comes from the cockpit. There are aircraft that have audio sources available outside the cockpit. "Aircraft audio recorder" might be a more descriptive term.

It is important to understand that there is an intercom system available to the flight crew. The crew often uses headsets or earpieces with boom microphones to communicate with each other through the intercom. However, in a relatively quiet cockpit, such as that found in many modern transport jets, in some situations it is possible the flight crew may communicate simply by talking to each other and bypassing the intercom system.

All cockpits must have reinforced, tamper proof doors and the cockpit must be inaccessible to unauthorized persons during flight. It is necessary for the flight deck crew to communicate with the flight attendant(s), so it is clear an intercom system must be present for this purpose.

The intercom system allows the flight crew to communicate with each other. Additionally, all radio communications with air traffic control, company dispatch, maintenance, and other sources is available to the crew using the same system. These communications are recorded through both the captain's and first officer's audio stream.

The actual connection between the audio source and the CVR is analog on most aircraft. Only the very newest generation of aircraft have digital audio systems. Once the data reaches the recorder, depending upon the type of recorder in use, it may be recorded on analog tape or in digital memory. In the case of digital recorders, which are usually referred to as "solid state" recorders, the process of digitizing the information occurs within the recorder itself [Source: S02].

1. Captain

The captain is a required flight crewmember with pilot-in-command authority over the flight. The captain may or may not manipulate the flight controls at any given time, but always has an active role in the conduct of the flight.

The captain occupies the left seat in the cockpit. The intercom channel from the captain's microphone is one of the primary inputs into the cockpit voice recorder.

Anything the captain says into the microphone is recorded, including conversation with other crewmembers and radio communications. If the captain chooses not to use the intercom to communicate with other members of the crew, it is possible some of the things said by the captain may not be recorded, or at least not recorded clearly.

2. First Officer

The first officer (FO) is a required flight crewmember with second-in-command authority over the flight. As is true of the captain, the FO may or may not manipulate the flight controls at any given time, but always has an active role in the conduct of the flight.

The intercom channel from the first officer's microphone is one of the primary inputs into the cockpit voice recorder.

The first officer occupies the right seat in the cockpit. Similar to the arrangement available to the captain, anything the FO says into the FO's microphone will be recorded, including conversation with other flight crewmembers, public address announcements to passengers and radio communications. But, conversation spoken directly to other crewmembers may not be recorded or not recorded clearly.

3. Cockpit Area Microphone

Early in the history of crash investigation when cockpit voice recorders became available, crash investigators discovered that significant amounts of useful information was not available to them if only the captain and first officer microphones were recorded.

The cockpit area microphone (CAM) is centrally located in the cockpit, not tied to an intercom channel, so that the sounds heard in the cockpit are available to crash investigators.

The cockpit area microphone is one of the primary inputs into the cockpit voice recorder.

The CAM picks up the sound of warning bells and chimes, landing gear lowering and retracting, certain flight control surfaces moving, engine noises, and any number of other sounds heard in the cockpit while in flight. It also picks up conversation, whether spoken directly between crewmembers or as they are using the intercom, although on the recordings this is often difficult or impossible to understand because the audio level of such conversations is similar to or not as loud as the ambient level of noise in the cockpit.

4. Cabin Microphone

Less common than the captain's microphone, first officer's microphone and cockpit area microphone, an aircraft may be equipped with one or more cabin microphones. These are usually found on larger aircraft or on the very newest aircraft.

The lead flight attendant may be stationed in a certain location. A cabin microphone may be found in that area.

Other locations for cabin microphones might be one or more in the passenger cabins, such as the upper deck of first class on a Boeing 747, first class, business class, and economy.

If installed, the cabin microphone(s) may be input(s) into the cockpit voice recorder.

C. FLIGHT DATA SOURCES

The source of the data recorded by the FDR is an array of sensors located around the aircraft. The sensors transmit data to the FDR through a digital data bus. The rate at which an individual sensor produces data varies from continuous to once per second or longer, although most measurable data items do not need extremely fast sampling rates to give investigators sufficient information about that item.

Broad categories of data sources are as follows. For more specific regulatory requirements, see section II.E.

1. Flight Situation

This is information about the aeronautical or flying situation of the aircraft, such as heading, altitude, airspeed, vertical speed and angle of attack.

2. Engine Condition

This is information about the performance and condition of the engine, such as RPM of the propeller or fan, engine pressure ratio and oil temperature.

3. Flight Control Inputs

This is information about what control inputs the pilots are making to cause the aircraft to do what it is doing, such as rudder pedal position, aileron control deflection, flap lever position and elevator control pressure.

4. Flight Control Situation

This is information about what the flight control surfaces are actually doing, as opposed to what the flight crew is trying to make them do through their flight control inputs, such as rudder deflection, aileron deflection, elevator deflection, trim tab position and flap deflection.

5. Environmental Situation

This is information about the environment in which the aircraft is flying, such as outside air temperature, wind speed and direction, type of precipitation experienced (rain, snow, sleet, etc.) and presence of ice.

D. VIDEO SOURCES

Although not mandated, one of the areas in which there is interest is cockpit video.

Even by recording the captain's microphone, FO's microphone and CAM, some of the flight crew's actions and communication relevant to crash investigation may be missed. Non-verbal gestures, such as a thumbs-up, can only be captured if there is a visual record of what happens in the cockpit.

Additionally, there are some displays showing information to the flight crew that are not usually recorded, such as the weather radar. Having a visual record of these otherwise un-recorded displays may provide important clues to accident investigators.

Video produces relatively a lot of data compared to flight data and voice. The volume of data depends largely upon such factors as whether the image is black-and-white or in color, the pixel resolution and the frame rate per second. The necessary frame rate is a matter of debate. The goal of using cockpit video in the first place is to provide adequate crash investigation data, not to watch a movie of the goings-on in the cockpit on a large home theatre system with surround sound. So, is it adequate to see maybe four frames per second, which makes the movements in the cockpit appear somewhat jerky, or do investigators need to see smooth movement at maybe thirty frames per second? For the purpose of this thesis, this question can remain unanswered, although the answer does significantly impact the volume of information any Real-Time Flight Data Transmission System must handle.

It should be noted that a video image of flight instruments that are recorded by other means, such as the indication of airspeed, altitude or heading, is probably not very useful. Only in the case where the instrument fails to show the proper value would there be a need to have a video image of it, but the probability of this situation occurring is essentially zero. Therefore, seeing *everything* the flight crew sees isn't strictly necessary.

One potential benefit of having cockpit video available is monitoring extremely unusual events in the cockpit. It might be nice to actually see such things as a terrorist breaking into the cockpit, seizing control, threatening the flight crew, and so on. On the other hand, simply knowing that it happened may be good enough. United Airlines flight 93, the so-called "fourth aircraft" hijacked by terrorists on September 11, 2001, which crashed in western Pennsylvania killing all souls on board, is a good example of an event where cockpit video may have answered many questions as to what went on aboard the aircraft. While we generally know what happened in this case, the families of the passengers and crew, as well as the public at large, desire to know more.

For the purpose of this thesis, cockpit video is of interest as a source of a large volume of data that must be considered when designing a remote transmission system.

E. REGULATORY REQUIREMENTS

The Federal Aviation Administration (FAA) requires the use of flight data recorders for certain aircraft. Not every flying machine must have such a device. The two factors that determine whether an aircraft must have flight recorders are the size of the aircraft and the operating environment.

1. Flight Recorder Regulations: Operations Other Than Air Carrier

a) All Aircraft

14 CFR Part 91 GENERAL OPERATING AND FLIGHT RULES applies to all aviation operations conducted within the jurisdiction of the United States. In general, private flying, agricultural flying, flight instruction, corporate aviation, gliders, balloons and airships do not require flight recorders unless the flying is done in large (which has a specific FAA definition) or multiengine turbine-powered aircraft.

FAR 91.609 specifies flight recorder requirements for large and transport category aircraft operated under Part 91. Because FAR 91 applies to all aircraft and other sections of 14 CFR apply specifically to various types of for-hire operations, the rules in Part 91 will most likely be superseded or added to by other rules, such as Part 135 (commuter and air taxi) or 121 (air carrier).

b) Commuter And On Demand (Air Taxi)

14 CFR Part 135 OPERATING REQUIREMENTS: COMMUTER AND ON DEMAND OPERATIONS AND RULES GOVERNING PERSONS ON BOARD SUCH AIRCRAFT applies to on demand air taxi operations and for-hire operations that do not have a set schedule. Examples include the charter of a small aircraft (air taxi) or a casino flying guests to their location (commuter). For large and multiengine turbine-powered aircraft operating under Part 135, FAR

135.152 specifies the exact data values that must be recorded. The list is essentially the same as the list found in the air carrier regulations (Part 121).

2. Flight Recorder Regulations: Air Carrier

14 CFR Part 121 OPERATING REQUIREMENTS: DOMESTIC, FLAG, AND SUPPLEMENTAL OPERATIONS applies to airlines. An understanding of the distinction between domestic, flag or supplemental carrier is not necessary for this thesis, but has to do with the size, schedule type and operating area of the air carrier operation.

For flight operations conducted under Part 121, FAR 121.343, FAR 121.344 and FAR 121.344a specify flight data recorder (FDR) requirements and FAR 121.359 specifies the requirements for cockpit voice recorders (CVR).

a) FAR 121.343(g)

The flight data recorder must be "operated continuously from the instant the airplane begins the takeoff roll until it has completed the landing roll at an airport".

b) FAR 121.343(h)

For recorders of recent manufacture, there must be 25 hours of recorded data. One hour of the oldest data may be erased for maintenance purposes and no record need be kept more than 60 days.

c) FAR 121.343(i)

If a flight is terminated due to a situation involving substantial property damage or loss of life, the data from the flight recorders must be kept for at least 60 days or longer, if required.

d) *FAR 121.343(d)*

Certain types of digital flight recorder systems must record the following data items:

1. Time
2. Altitude
3. Airspeed
4. Vertical acceleration
5. Heading
6. Time of each radio transmission either to or from air traffic control
7. Pitch attitude
8. Roll attitude
9. Longitudinal acceleration
10. Pitch trim position
11. Control column or pitch control surface position
12. Control wheel or lateral control surface position
13. Rudder pedal or yaw control surface position
14. Thrust of each engine
15. Position of each thrust reverser
16. Trailing edge flap or cockpit flap control position
17. Leading edge flap or cockpit flap control position

e) *FAR 121.344*

Newer digital flight recorders must record the following data items:

1. Time
2. Pressure altitude
3. Indicated airspeed
4. Heading -- primary flight crew reference (if selectable, record discrete, true or magnetic)
5. Normal acceleration (Vertical)
6. Pitch attitude
7. Roll attitude
8. Manual radio transmitter keying, or CVR/DFDR synchronization reference
9. Thrust/power of each engine -- primary flight crew reference
10. Autopilot engagement status
11. Longitudinal acceleration
12. Pitch control input

13. Lateral control input
14. Rudder pedal input
15. Primary pitch control surface position
16. Primary lateral control surface position
17. Primary yaw control surface position
18. Lateral acceleration
19. Pitch trim surface position or parameters of paragraph (a)(82) of this section if currently recorded
20. Trailing edge flap or cockpit flap control selection (except when parameters of paragraph (a)(85) of this section apply)
21. Leading edge flap or cockpit flap control selection (except when parameters of paragraph (a)(86) of this section apply)
22. Each Thrust reverser position (or equivalent for propeller airplane)
23. Ground spoiler position or speed brake selection (except when parameters of paragraph (a)(87) of this section apply)
24. Outside or total air temperature
25. Automatic Flight Control System (AFCS) modes and engagement status, including autothrottle
26. Radio altitude (when an information source is installed)
27. Localizer deviation, MLS Azimuth
28. Glideslope deviation, MLS Elevation
29. Marker beacon passage
30. Master warning
31. Air/ground sensor (primary airplane system reference nose or main gear)
32. Angle of attack (when information source is installed)
33. Hydraulic pressure low (each system)
34. Ground speed (when an information source is installed)
35. Ground proximity warning system
36. Landing gear position or landing gear cockpit control selection
37. Drift angle (when an information source is installed)
38. Wind speed and direction (when an information source is installed)
39. Latitude and longitude (when an information source is installed)
40. Stick shaker/pusher (when an information source is installed)
41. Windshear (when an information source is installed)
42. Throttle/power lever position
43. Additional engine parameters (as designated in Appendix M of this part)
44. Traffic alert and collision avoidance system
45. DME 1 and 2 distances
46. Nav 1 and 2 selected frequency

47. Selected barometric setting (when an information source is installed)
48. Selected altitude (when an information source is installed)
49. Selected speed (when an information source is installed)
50. Selected mach (when an information source is installed)
51. Selected vertical speed (when an information source is installed)
52. Selected heading (when an information source is installed)
53. Selected flight path (when an information source is installed)
54. Selected decision height (when an information source is installed)
55. EFIS display format
56. Multi-function/engine/alerts display format
57. Thrust command (when an information source is installed)
58. Thrust target (when an information source is installed)
59. Fuel quantity in CG trim tank (when an information source is installed)
60. Primary Navigation System Reference
61. Icing (when an information source is installed)
62. Engine warning each engine vibration (when an information source is installed)
63. Engine warning each engine over temp. (when an information source is installed)
64. Engine warning each engine oil pressure low (when an information source is installed)
65. Engine warning each engine over speed (when an information source is installed)
66. Yaw trim surface position
67. Roll trim surface position
68. Brake pressure (selected system)
69. Brake pedal application (left and right)
70. Yaw or sideslip angle (when an information source is installed)
71. Engine bleed valve position (when an information source is installed)
72. De-icing or anti-icing system selection (when an information source is installed)
73. Computed center of gravity (when an information source is installed)
74. AC electrical bus status
75. DC electrical bus status
76. APU bleed valve position (when an information source is installed)
77. Hydraulic pressure (each system)
78. Loss of cabin pressure
79. Computer failure

80. Heads-up display (when an information source is installed)
81. Para-visual display (when an information source is installed)
82. Cockpit trim control input position -- pitch
83. Cockpit trim control input position -- roll
84. Cockpit trim control input position -- yaw
85. Trailing edge flap and cockpit flap control position
86. Leading edge flap and cockpit flap control position
87. Ground spoiler position and speed brake selection
88. All cockpit flight control input forces (control wheel, control column, rudder pedal)

F. ORGANIZATIONAL ROLES IN ACCIDENT INVESTIGATION

Various entities play a role in air crash accident investigation. This section describes the organizational role of each of the major participants in the process.

1. Federal Aviation Administration (FAA)

The FAA is an agency of the United States Department of Transportation (DOT). It has regulatory oversight of all aviation activities within the jurisdiction of the United States.

It is the FAA's organizational role in air crash investigation to the specify equipment requirements pertaining to flight data recorders and the data handling requirements for the information recorded by them.

One of the FAA's primary concerns is the safety of flight. The classic paradox facing the FAA is that its other primary concern is the promotion of aviation and air commerce. These two primary concerns can be at odds. For example, the crash of Valuejet 592 may have resulted from compromised safety practices in favor of continued air commerce. But, it is generally such that safety wins every time there is a conflict. Better safety translates directly to more aviation activity and healthier air commerce.

2. National Transportation Board (NTSB)

The National Transportation Safety Board is an independent Federal agency. Congress gives it the authority and mission to investigate every civil aviation accident in the United States. The NTSB is also concerned with significant accidents in the other modes of transportation, such as railroad, highway, marine and pipeline. It issues safety recommendations aimed at preventing future accidents.

The organizational role of the NTSB in air crash investigation is to actually conduct the crash investigation, to report the probable cause of the accident, and to make recommendations to the FAA for enhancing aviation safety. The FAA receives the NTSB's recommendations, but is not obligated to act upon them.

The NTSB has field investigation teams that travel to the site of air crashes and collect all available information from the site. To properly respond to more significant accidents, these "Go Teams" are on continuous call and can respond very quickly at any time.

The NTSB maintains laboratories that analyze crash data collected from crash sites. These laboratories examine flight recorder information.

A key task of the NTSB is to determine "probable cause" for the accident. By analyzing many factors, including weather, flight crew actions, flight crew training, flight crew medical condition, maintenance status of the aircraft, air traffic control and more, the NTSB is nearly always able to determine sequence of events in the accident chain. This process results in determination of probable cause.

The availability of flight data, whether taken from flight recorders that were on board the accident aircraft or, in speculation, retrieved from a database on the ground where real-time flight data was transmitted, is a critical component of accident investigation. Such data must be available in a timely manner. It must also be accurate, complete and un-compromised. Accordingly, any system for real-time transmission of flight data must deliver timely, accurate and complete data to the NTSB.

a) NTSB 830

NTSB regulation 830 NOTIFICATION AND REPORTING OF AIRCRAFT ACCIDENTS OR INCIDENTS AND OVERDUE AIRCRAFT, AND PRESERVATION OF AIRCRAFT WRECKAGE, MAIL, CARGO, AND RECORDS sets forth the regulatory requirements for accident reporting.

The most important feature of NTSB 830 as related to a real-time data transmission system is that it is referenced by FAR 121, which cites NTSB 830 to require the release of flight data under certain circumstances, such as the termination of a flight due to significant property damage or loss of life. This has direct implication on the characteristics of a database used to store flight data received from a real-time transmission system. Such a system must be able to respond to the requirements of timely release of stored information, accuracy of the information, and length of time the data is stored.

3. Operator (Airline)

The organizational role of the operator is to cooperate with both the FAA and the NTSB in the crash investigation by releasing the flight recorder data from the accident flight. They clearly have a vested interest in flight safety and will provide whatever support and assistance they can to help determine the probable cause of the accident, and will modify procedures and practices in the direction of enhanced flight safety.

Operators have thousands of flights every day, all of which have flight recorders that collectively record a huge volume of flight data. This data is the property of the operator until it must be released in accordance with NTSB 830 and 14 CFR.

4. Equipment Manufacturer

Equipment manufacturers, such as Boeing, Airbus, Dassault, Canadair, Embraer, Beechcraft, Cessna and others, are critically interested in flight safety and in building safe aircraft. Their organizational role in accident investigation is such that they are often called upon to provide technical details about the accident aircraft, conduct engineering tests on recovered parts and components, or participate in technical discussions in an advisory capacity.

During the design and manufacture of airframes, the equipment manufacturers provide for availability of placement of flight data sensors, a pathway from the sensors to the flight recorders, and a for *a place for flight recorders to go on the aircraft*. None of the aircraft manufacturers makes flight recorders (*see section II.J*). Flight recorders are purchased from a separate vendor and installed in the airframe. Generally, aircraft manufacturers participate in the process by installing flight recorders required by the FAA and purchased by their customers, but they do not drive the nature of the recorders themselves or the data they must collect.

G. CRASH STANDARDS FOR FLIGHT RECORDERS

This section describes the minimum standards for survivability of flight data recorders and cockpit voice recorders. Some flight recorder manufacturers choose to engineer their products to exceed the minimum standards. The National Transportation Safety Board (NTSB) issues standards for recorder survivability. The FAA issues regulations specifying how recorders are to be used, but not crash survivability standards.

1. Cockpit Voice Recorders

Table 1 shows crash standards for cockpit voice recorders (CVR) [Ref: N03] .

ITEM	STANDARD
Time recorded	30 minutes continuous 2 hours for solid state digital units
Number of channels	4
Impact tolerance	3400 Gs / 6.5ms
Fire resistance	1100°C / 30 min
Water pressure resistance	Submerged 20,000 ft
Underwater locator beacon	37.5 KHz
Battery	6yr shelf life 30-day operation

Table 1. NTSB Cockpit Voice Recorder Standards

2. Flight Data Recorders

Table 2 shows crash standards for flight data recorders (FDR) [Ref: N03].

ITEM	STANDARD
Time recorded	25 hours continuous
Number of parameters	5 to 300+
Impact tolerance	3400 Gs / 6.5ms
Fire resistance	1100°C / 30 min
Water pressure resistance	Submerged 20,000 ft
Underwater locator beacon	37.5 KHz
Battery	6yr shelf life 30-day operation

Table 2. NTSB Flight Data Recorder Standards

3. Real-Time Flight Data Transmission System

A real-time remote flight data recording system will have different requirements than on-board flight recorders. The real-time remote system will transmit flight data to the recording computer on a flight-by-flight basis. No flight is more than about 15 hours, except military flights with air-to-air refueling. Examples of the longest flights are those from the United States to Australia. A flight from Sydney to Los Angeles usually takes approximately 12.5 hours, whereas a flight from Los Angeles to Sydney lasts approximately 14 hours [Source: D01].

The design of a real-time remote flight data recording system should respect the "time recorded", "number of channels", and "number of parameters" standards. The remainder of the standards do not apply because they exist to protect flight data contained within the on-board recording devices as tremendous impact forces destroy the aircraft carrying them. These standards are not necessary for real-time remote recording because data is not stored in an on-board recording device.

Table 3 provides a summary of proposed standards for a real-time flight data transmission system.

REAL-TIME FLIGHT DATA TRANSMISSION SYSTEM

ITEM	STANDARD
Time recorded	25 hours continuous flight data 2 hours voice
Number of parameters	5 to 300+
Number of voice channels	4

Table 3. Recommended Standards For Real-Time Remote Flight Data Recording Systems

H. COMPUTER NETWORKS ABOARD AIRCRAFT

It is not common to find a computer network aboard most aircraft. There is no ethernet, token ring, AppleTalk® or other kind of packet-based network available, although some manufacturers (i.e. Boeing Aircraft Company) may include such a network on future generations of aircraft [Source: S02].

I. DIGITAL VERSUS ANALOG SENSORS

This section describes which flight data and voice sensors are digital and which are analog.

1. Digital Sensors

In general, most flight data sensors produce digital output. The value might be a numerical value, such as airspeed expressed in knots or mach, or a coded digital value, such as (for example) deflection of the aileron on a scale of 0=none to 255=full.

In the case of numerical value sensors, the nature of the value itself serves as its own reference. For example, we know that airspeed is expressed in knots. The value reported and recorded is the value expressed directly. There is no ambiguity.

In the case of coded digital values, there is a need for reference data to be included as well as the data value itself. The reference data gives the limits of possible data values or some other context in which to interpret the reported value.

One of the problems that can significantly delay crash investigation is interpretation of data values recorded on the flight data recorder. Without reference data, crash investigation may require tedious and exhausting investigative work to positively determine the meaning of the information recorded on the FDR.

As related to a real-time remote data transmission system, when considering data transmission media, the capacity of the required data network and the capabilities of the recording computer system, it is necessary to account for not only the data parameters themselves, but also the reference data that must be transmitted to give meaning to the data parameters [Ref: S02].

2. Analog Sensors

In general, voice data is analog until it reaches the cockpit voice recorder. In the case of a solid-state, digital cockpit voice recorder, the voice stream is digitized and then recorded. In the case of an analog tape recorder, it is simply recorded.

J. MANUFACTURERS OF RECORDERS

There are approximately 30 manufacturers of digital flight recorders. Aircraft manufacturers, such as Boeing and Airbus, install flight recorders on their airframes that are obtained from a recorder manufacturer. Two prominent recorder manufacturers that supply their products for installation on Boeing aircraft are L3 Communications in Sarasota, Florida, and Honeywell Corporation in Renton, Washington [Source: S02].

K. SECURITY THREAT

This section provides a security threat assessment and residual risk assessment of the present state-of-the-art of flight data recording.

1. Threat Assessment

Even during the tragic events of September 11, 2001, there was no assault on the flight data of any of the flights that were involved in the attack. This is perhaps the most extreme example of terrorist activity we have seen thus far and the flight data was not affected. Although we did not recover all of the FDRs and CVRs, if we had, the data would have been accurate. Although not supported by research, to the author's knowledge there has not been a security compromise of flight data or cockpit voice information in any aviation disaster.

In the air, there appears to be a very low threat against compromise of flight data and cockpit voice information. Hijackers and terrorists have other things to worry about and are not very concerned with flight data. If we ever see a situation where hijackers are concerned with what is being fed to the FDR and CVR, they will likely only be able to disrupt cockpit voice data by destroying the sensors — the headsets worn by the flight crew or, if they know the location of it, the cockpit area microphone. Sensors for data going to the flight data recorder are inaccessible from the flight deck or passenger cabin.

2. Risk Assessment

Present recording systems are entirely contained within the aircraft. Given that the threat is very low, there is little risk to the recorded flight data.

Risks include:

- Intentional vandalism of input devices used to collect cockpit voice information
- Total electrical system failure
- Intentional disruption of electrical power
- Physical removal or destruction of the flight recorders from the accident site

None of these risks are considered significant, thus the present flight data recording scheme is considered secure.

III. TRANSMISSION OF FLIGHT DATA OFF AIRCRAFT

A. INTRODUCTION

This chapter discusses five presently available data transmission media that could be used, either singly or in combination, to implement a Real-Time Flight Data Transmission System.

The term "data transmission medium" is used to refer to the radio transmission vehicle for the transmitted signal, including SATCOM, UHF, VHF, HF and Radar.

B. TRANSMISSION MEDIUM CHARACTERISTICS

Table 4 presents characteristics of the transmission media that are discussed in this chapter. Particulars about the five transmission media are presented using this table as a template.

The listed characteristics are important points to consider when evaluating transmission media. On the basis of these factors, an assessment can be made about the suitability of the particular transmission medium for a given situation.

The frequency at which the medium operates affects the bandwidth, which is the amount of data the medium can be expected to carry.

The geographic coverage area is important when considering what medium to use in a particular area.

Reliability, limitations, strengths, weaknesses and vulnerabilities are factors that affect the usability and assurance of the medium.

Cost is obviously an important factor.

TRANSMISSION MEDIUM CHARACTERISTICS

CHARACTERISTIC	DISCUSSION
Frequency Range	Describe the range of frequencies on the radio spectrum in which the medium operates.
Bandwidth	(1) Describe the volume of information that can be transmitted using the medium. For digital signals, usually expressed in bits per second transmission rate. For analog systems, usually expressed in frequency width of the signal. (2) [Definition] The amount of data carrying capacity sold or used.
Reliability	Describe the degree of confidence that the medium can be relied upon to faithfully transmit data.
Limitations	Describe features about the medium that imposes boundaries on its use.
Geographic Coverage Area	One tenant of the Real-Time Flight Data Transmission System is that it should offer worldwide coverage. Describe the area or areas of the world where the medium can be received.
Strengths	Describe features about the medium that enhances its utility.
Weaknesses	Describe features about the medium that detracts from its utility.
Cost	Describe the relative cost to use the medium. Consider cost of equipment, bandwidth and maintenance.
Vulnerabilities	Describe general types of vulnerabilities to which the signal is susceptible, including human threats and weather disruptions.

Table 4. Discussion Points For Transmission Media

C. DATA TRANSMISSION MEDIA

This section describes five presently available data transmission media (radio systems) that could be used, either singly or in combination, to implement a Real-Time Flight Data Transmission System.

No single transmission medium is suitable for all situations. Satellite communications provide clarity, reliability and worldwide signal coverage, but the cost is prohibitive and signal acquisition is questionable during the most critical moments of a crash sequence. VHF radios are ubiquitous in aviation and cost effective, but they are ineffective over remote areas and oceans and have limited channel capacity. HF is low cost and offers long-range propagation, but the bandwidth, susceptibility to interference and signal reliability is not good.

To implement a Real-Time Flight Data Transmission System, combining several different transmission media is recommended to best handle different operating areas and flight conditions. This provides the greatest chance for data to be transmitted and received during all phases and critical moments of flight.

Table 5 presents the characteristics of Satellite (SATCOM) systems.

Table 6 presents the characteristics of UHF systems.

Table 7 presents the characteristics of VHF systems.

Table 8 presents the characteristics of HF systems.

Table 9 presents the characteristics of Radar (Transponder) systems.

1. SATCOM System

CHARACTERISTIC	DISCUSSION
Frequency Range	C–band (6 GHz transmit, 4 GHz receive), L–band (950-1535 MHz), Ka-band (30 GHz transmit, 20 GHz receive), Ku–band (14 GHz transmit, 12 GHz receive) [Ref: T02]
Bandwidth	Almost any bandwidth required by the Real-Time Flight Data Transmission System. The limitation is cost.
Reliability	With good signal acquisition, reliability is high while transmitting. Mobile transceiver systems exist for aircraft use. They maintain signal acquisition as the aircraft makes normal maneuvers.
Limitations	Satellite acquisition must be maintained and can easily be lost. The number of available satellite communication channels and total available bandwidth is limited; satellite capacity may be an issue.
Geographic Coverage Area	Worldwide.
Strengths	High reliability, worldwide signal coverage, sufficient bandwidth for future volume of data expansion.
Weaknesses	High cost of bandwidth and equipment. Potential for loss of satellite acquisition during flight at unusual attitudes as may be experienced in a crash sequence.
Cost	Relatively high for both bandwidth and equipment.
Vulnerabilities	Relatively few. The signal is a narrow beam and therefore not as easy to jam as other types of signals, however spoofing is possible if the attacker has SATCOM equipment and can generate signals that act like an aircraft in flight.

Table 5. Characteristics Of SATCOM Systems

2. VHF Radios

CHARACTERISTIC	DISCUSSION
Frequency Range	117-137 MHz (aviation use)
Bandwidth	Data rates up to 31.5 kbps [Ref: N06]
Reliability	Very reliable when properly implemented.
Limitations	Line-of-sight propagation. Useful range 100-120NM.
Geographic Coverage Area	Within relatively short distance of receiver; remote area and oceanic coverage not available using ground stations (none exist), but may be possible using air-to-air network.
Strengths	Low cost. Reliable. Uses commonly available equipment, both airborne and ground. Receiver network already exists in much (most) of the world. All aircraft have VHF radios installed, including antennae systems. Using existing radios or adding a dedicated one for flight data transmission is relatively easy.
Weaknesses	Can suffer signal drop out. Coverage not available in remote areas or over oceans and in polar regions. Not directional. Limited channel capacity.
Cost	Relatively low.
Vulnerabilities	Easy to jam signal. Easy to spoof signal.

Table 6. Characteristics Of VHF Communications

3. UHF Radios

CHARACTERISTIC	DISCUSSION
Frequency Range	300 Mhz to 3 GHz
Bandwidth	Data rates up to 115.2 kbps [Ref: H02]
Reliability	Excellent.
Limitations	Line-of-sight propagation. Less forgiving of obstructions in signal path than VHF. Useful range 100-120NM.
Geographic Coverage Area	Within relatively short distance of receiver; remote area and oceanic coverage not available.
Strengths	Low cost. Reliable. High bandwidth.
Weaknesses	Not common in the civilian world. Adds another radio and antenna system to most (if not all) civil aircraft. Limited channel capacity.
Cost	Slightly higher than VHF, but not exceptionally high.
Vulnerabilities	Although equipment is less common than VHF equipment, the vulnerabilities are essentially the same. Easy to jam signal. Easy to spoof signal.

Table 7. Characteristics Of UHF Communications

4. HF Radios

CHARACTERISTIC	DISCUSSION
Frequency Range	3 MHz to 30 MHz
Bandwidth	Relatively low due to the low frequency of the carrier.
Reliability	Highly susceptible to atmospheric interference, skip, signal collision. Signal routinely drops out with changing ionosphere conditions. Lots of noise even on a "clear" signal making digital transmission questionable if not nearly impossible.
Limitations	Not suitable for data transmission use in bad weather due to disruption of signal by electrical discharge (lightning).
Geographic Coverage Area	Wide. Oceanic and remote area coverage is available.
Strengths	Good signal coverage. HF is used for transoceanic communication and was the standard before the advent of satellite communications. It is still in widespread use and is required equipment for transoceanic flights.
Weaknesses	Reliability and bandwidth are low.
Cost	Medium. A large percentage of civil aircraft do not have HF equipment, especially those aircraft used for domestic routes. It would have to be installed to be part of a data transmission system. Long haul aircraft have HF radios and antenna systems.
Vulnerabilities	HF is highly susceptible to atmospheric disturbance that causes significant signal degradation, fading and drop out. Easy to jam signal. Easy to spoof signal.

Table 8. Characteristics Of HF Communications

5. Radar (Transponder)

CHARACTERISTIC	DISCUSSION
Frequency Range	L–band (950-1535 MHz).
Bandwidth	Expect >115.2 kbps data rate.
Reliability	Relatively high.
Limitations	Exceptionally line-of-sight coverage. One frequency per radar system split between all aircraft served at any given time significantly limits data bandwidth available to each aircraft.
Geographic Coverage Area	Most of the United States is covered by radar, although large areas of the Western U.S. are outside radar coverage or require the aircraft to be at higher altitudes to be "seen". Alaska has vast areas that are non-radar. Oceans are not covered by radar.
Strengths	Good signal quality.
Weaknesses	Burst transmissions required. Can only transmit when the radar antenna sweeps through the position of the aircraft.
Cost	If currently installed transponders could be used to transmit data, cost is low because every aircraft seeking to use a Real-Time Flight Data Transmission System has at least one transponder.
Vulnerabilities	Requires relatively uncommon equipment to jam the radar signal. Not as easy to spoof as other signals due to the very directional nature of the radar signal.

Table 9. Characteristics Of Radar/Transponder Communications

D. DATA TRANSMISSION METHODS

This section discusses several methods that could be used to transmit the data including *continuous broadcast*, *burst*, *broadcast when in trouble*, and *transmission to nearby aircraft*. The background knowledge is necessary when considering data link security.

Flight data and cockpit voice audio streams are constantly generated during all phases of a flight. Multiplied by all aircraft operating at any one time (approximately 4-5,000 over the United States), there is a significant amount of data to be moved (*see also chapter V, section B.1*).

Most flights are routine and do not end in an accident requiring flight data analysis. Therefore, the flight data generated by most flights is of little or no use from an accident investigation point of view. If there is no purpose for transmitting flight data other than to have it available in the event of an accident, then there is the potential to transmit a huge volume of information that will never be used.

Examining methods aimed at reducing the amount of transmitted flight data is an important factor that should be considered when designing the data transmission network.

1. Continuous Broadcast

Continuous broadcast refers to continuously transmitting flight data and cockpit voice streams as they are created.

According to Frank Doran, Senior Engineer for L3 Communications, a major manufacturer of flight data recorders, the bandwidth required per second is 120Kbps for cockpit voice and 3Kbps for flight data, or a total of 123Kbps. With cockpit video included, this adds another 1.6Mbps, for a total of 1.723Mbps [Ref: D03].

VHF and UHF data links offer about 115Kbps bandwidth, which nearly covers the requirement for cockpit voice and flight data, but does not account for cockpit video. To transmit voice, data and video, SATCOM links would be required or multiple VHF or UHF links could be used. SATCOM links, one per flight, is an expensive proposition. Multiple VHF/UHF links is a tricky problem in data splitting and recombination.

2. Broadcast When In Trouble (Intelligent Aircraft)

Noting that most flight data comes from routine flights that require no accident investigation, an idea to reduce the amount of flight data system-wide is to only transmit when a flight is experiencing unusual flight conditions.

The regime of normal flight is well understood. The Real-Time Flight Data Transmission System could incorporate a flight-monitoring computer that continuously compares the present flight condition with a definition of "normal". If the computer determines that flight conditions are not normal, it could then instruct the real-time system to transmit an appropriate amount of stored flight data (whatever is available in the flight recorders) and begin continuous broadcast of flight data. Once the computer determines the flight is not normal at any point, the system should not revert to not transmitting data until the flight is recovered (lands) and the system is reset.

"Broadcast when in trouble" has advantages in that the amount of transmitted flight data system-wide would decrease dramatically, saving costs, bandwidth and data exposure.

"Broadcast when in trouble" has disadvantages in that when the determination is made that the flight is not normal, the flight may abnormally terminate (crash) before there is adequate time to transmit the necessary volume of stored flight data.

3. Transmission To Other Nearby Aircraft

SATCOM appears to be a viable answer to the question of which transmission medium to use because of its ubiquitous, global coverage and excellent signal characteristics. But, it is expensive and difficult to maintain signal acquisition when the aircraft is flying in unusual flight attitudes — such as in the last few moments before the crash when the investigators really need the flight data. Sufficient channel availability is questionable if a large number of aircraft require the use of SATCOM at the same time.

To make use of more economical transmission means, nearby aircraft can be used as receivers. Almost always, every flight is in the vicinity of at least one other flight. "Vicinity" such that it is possible to transmit a VHF or UHF signal to that aircraft. Making use of this notion, the transmitting flight could transmit to another aircraft — using either the continuous or broadcast-when-in-trouble methods — that would then re-transmit the data to the ground or store it in on-board systems for later retrieval and analysis. Both aircraft would be transmitting to each other. The probability that both aircraft would crash is considerably lower than the probability that either aircraft might crash.

The most complex problem of the transmission-to-nearby-aircraft method is data reassembly. This can be addressed by proper data tagging and eventual re-transmission to a recording computer on the ground, which would then have the task of storing this data with other data from the accident flight.

4. Burst Transmission

Burst transmission involves saving data as it is generated, compressing it and transmitting all the saved data at once. There are relatively long periods of radio silence followed by relatively short periods of transmission. This method of transmission requires a computer to store the information before it is transmitted because present flight data recorders do not have the ability to simultaneously read and write data [Ref: D03].

The system is composed of an on-board computer that receives data headed for the flight recorders, storing it and then releasing it to be transmitted at some interval. The interval could be regular (e.g. once per hour, minute, or second) or triggered by some event (e.g. abnormal flight condition or availability of data link lock).

A cornerstone of burst transmission is compression of the data. A computer on-board the aircraft would store and compress the flight data until it is time to transmit. By offering long intervals of inactivity followed by short intervals of data transmission, the problems of frequency congestion and inadequate channel capacity are mitigated.

But the main problem with burst transmission is *what happens if the aircraft crashes between bursts?* The last few seconds of the crash sequence are of particular interest to crash investigators.

E. TECHNICAL CONSIDERATIONS

This section explains some technical considerations about data transmission, including the equipment necessary to transmit the various types of signals, signal acquisition issues and issues on board the aircraft concerning connection with the data network (see next chapter) that carries the data to the ground computer, including the information assurance aspect of encryption key management.

1. Necessary Equipment

This section describes the equipment necessary to collect flight data and transmit it off the aircraft.

a) *Data Collection And Storage Equipment*

Digital Flight Data Recorders (DFDRs) have digital memory capable of storing the FAA-mandated 25 hours of flight data and 30 minutes of cockpit voice data (most actually store 2 hours of cockpit voice data). The memory is a circular buffer. The memory is always full and the oldest data is overwritten as new data comes in. Note: equipment manufacturers do not state the size of recorder memory in MB but rather in terms of *time*, since this is the measure used by the FAA in determining whether or not the recorder complies with regulations.

Because the recorder is always recording, it is not possible to also read from it at the same time. Therefore, it is not possible to use the flight recorders as the buffer if burst transmission is used [Ref: D03].

Flight data generated by the sensors around the aircraft is not necessarily in a transmittable format. Cockpit voice arrives at the flight recorders as an analog signal. Both flight data and cockpit voice audio needs processing for it to be in a transmittable format. A dedicated computer is therefore necessary to receive data from the aircraft as do the flight recorders, digitize it or reformat it into a transmittable data item according to the transmission protocol in use (possibly TCP/IP), and deliver it to the radio system that transmits it off the aircraft. This computer can be programmed to operate in continuous or burst mode, and to respect regular burst intervals or irregular intervals stimulated by an outside event.

Figure 8 shows the on-board components of the Real-Time Flight Data Transmission System. RTFDTS components are shown inside the hashed line. Existing components are shown outside the hashed line.

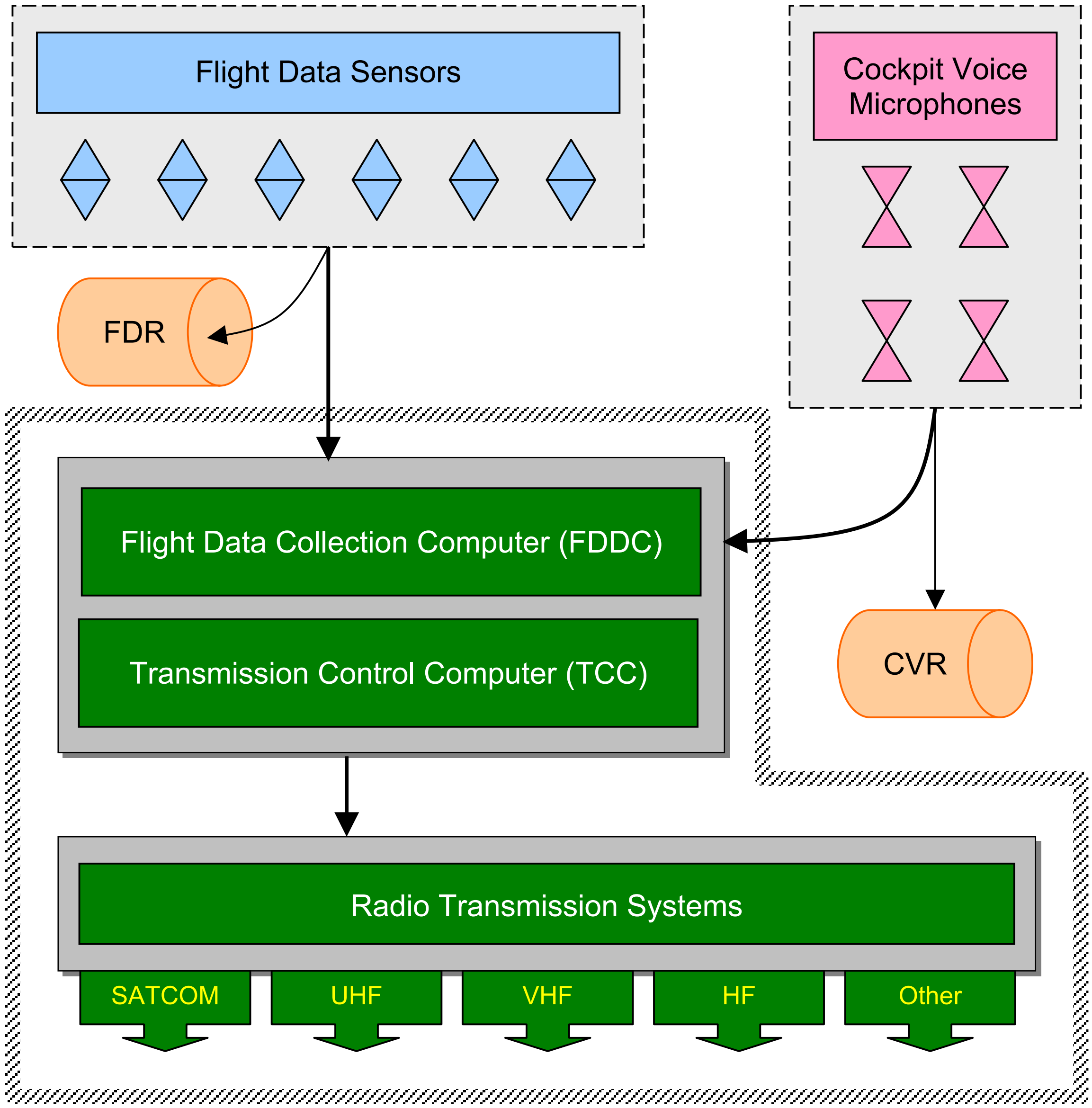

Figure 8. On-Board Real-Time Transmission System Components

b) Transmitters And Antenna Systems

According to Timothy Ridgely of Boeing Aircraft Company, one can assume a new Boeing aircraft will have two VHF transceivers. Most aircraft have more equipment than this, but that is the baseline [Ref: R01,S02]. Civil aircraft do not have UHF radios. When used on transoceanic routes, aircraft will have HF radios and SATCOM may also be installed.

Table 10 shows what radios will be available for various aircraft configurations.

AVAILABLE RADIOS FOR VARIOUS CONFIGURATIONS

CONFIGURATION	EQUIPMENT
Baseline	-Two VHF radios. These are already allocated for ATC and company communications and thus are not available for data link use. -At least one transponder. -Civil aircraft do not have UHF, HF or SATCOM equipment in the baseline.
Operator Dependent	Discretion to add any number of radios. Most equip their aircraft with more than the baseline of two VHF radios, but again all presently installed additional radios are allocated to some purpose and are almost surely not available for data link use.
With ACARS System	Adds one VHF radio.
Military	Adds UHF radio(s).
Transoceanic	Adds HF and *may* add SATCOM.

Table 10. Available Radios For Various Configurations

The conclusion is that to install a real-time flight data transmission link, for a typical aircraft in the civil fleet it cannot be assumed there are available transmitters of any type waiting to be dedicated to or shared with the system. For the real-time transmission system, additional transmitters must be installed, including their appropriate antenna systems.

2. Signal Acquisition And Availability

When a new receiver is selected, the aircraft must "connect" to the receiver by way of signal acquisition.

a) SATCOM

In the case of SATCOM, signal acquisition is the process of linking up the satellite with the "earth station" (the aircraft). This requires precise alignment of the antenna with the satellite, but normal maneuvering of the aircraft is not a problem for present SATCOM systems.

The big problem anticipated with SATCOM is loss of signal (loss of data) during critical phases of flight involving unusual flight attitudes. Consider the final flight path of Alaska Airlines flight 261, which crashed into the Pacific Ocean off the Southern California coast on January 31, 2000. In this example, the aircraft is noted on the CVR transcript to be inverted as well as flying in other unusual flight attitudes [Ref: N04]. In fact, the aircraft plunged into the ocean while following a corkscrew flight pattern involving extreme angles of pitch, roll and yaw. Almost certainly, any SATCOM signal emanating from an aircraft following this type of flight pattern would be lost. But, those are the critical moments of flight that are of particular interest to crash investigators.

b) VHF/UHF

VHF and UHF signals are not particularly difficult to acquire, although they have line-of-sight characteristics. Therefore, VHF/UHF signals are susceptible to attenuation, either partial or full, when objects intervene between the antenna and the receiver. It is possible that unusual flight attitudes could induce signal attenuation sufficient to prevent data transmission for brief or longer periods, causing loss of reception of flight data. This may happen as aircraft parts move into position and shield the signal from the ground receiver.

It is widely known that there is a reception pattern associated with VHF/UHF receivers. Mountains, buildings or other obstructions create these patterns by shielding the receiver from view of certain areas of the airspace. It is particularly critical to know the reception pattern for receivers used as part of the system and consider this information when designing preferred signal patterns for use by the Transmission Control Computer.

To acquire a signal, the aircraft transmitter requires a receiver on the ground or another aircraft in the vicinity to which it can connect and there must be a clear radio frequency on which to transmit.

Aviation communications traditionally use a single frequency to serve a number of aircraft, similar to a telephone party line. Exactly one aircraft (or the ground controller) can talk on the frequency at any one time. It is unfortunately common for two pilots to "step on" each other, which is the situation when two pilots attempt transmit at once. To help alleviate this problem, pilots are taught to LISTEN on frequency to be sure it is clear before keying up to transmit.

The "party line" idea has served well for many years for aviation voice communications, but it is based upon each pilot transmitting for a relatively short period of time and then releasing the frequency for another pilot's use. The RTFDTS has the need to *continuously* broadcast data.

There is limited channel capacity in the aircraft VHF and UHF frequency spectrum. Channels could be allocated for continuous broadcast of flight data, but this will likely lead quickly to exhaustion of available data link channels. Using techniques such as compression of data, transmitting in short bursts, and time-division of the frequency, the problem of frequency congestion could be reduced or eliminated. RTFDTS communications could probably be accomplished with fewer frequencies allocated to the system.

Alternately, the aircraft could simply hold the data for later transmission as in the burst transmission method, but it is possible that the aircraft might crash before it can acquire a data link, leading to loss of data available to crash investigators.

F. INFORMATION ASSURANCE ISSUES

This section discusses the information assurance issues on the aircraft from the point the data is generated to the point it leaves the aircraft.

This discussion includes the sensor or microphone, the data pathways around the aircraft, the flight recorders and the radios used to transmit the data off the aircraft. For each part, the basic information assurance concerns of *confidentiality*, *integrity*, *authenticity* and *availability* are discussed.

1. Flight Data Sources

Flight data is generated either by sensors located at various points around the aircraft or by the flight management computers. It is impossible or highly problematic to access the data sources while in flight. On the ground, sensors can be accessed and could be subject to tampering. In flight or on the ground, there are no controls that would allow anyone to alter what the flight management computers report to the flight recorders.

Except as noted below, because of the physically isolated nature of flight sensors from the passenger and crew areas of the aircraft, there are no significant issues affecting confidentiality, integrity, authenticity or availability of the data generated by flight data sensors.

An attacker could adversely affect the availability of flight data reported by the flight management computer by switching off the computer. However, this may have the added effect of causing the aircraft to crash, since in some cases the flight computer actually flies the aircraft (fly-by-wire designs) using inputs from the pilots and other sources.

An attacker could also inhibit the availability of data by physically destroying flight instruments or reaching behind the panel and disconnecting them. There is, after all, a required crash axe in the cockpit (FAR 121.309e).

2. Cockpit Voice And Other Audio Sources

Audio, including cockpit voice and cabin audio, is generated by devices that are accessible to persons in the cockpit or cabin.

An attacker could disable these devices to prevent recording, thus adversely affecting the availability of the information, by physically destroying them, unplugging headsets or covering microphones with sound muffling material. Also, if attackers communicate by whispering or using hand gestures, this circumvents the recording of their communication and is, in a sense, an adverse affect on the availability of audio information.

If an attacker physically tampers with or vandalizes a microphone, but the microphone still partially works, this straddles the line between adversely affecting the availability of the audio stream and the integrity of the information it produces.

There are no issues of confidentiality or authenticity associated with cockpit voice or cabin area audio.

3. Pathway Between Sensor Or Microphone And Recorder

There are a large number of cables and wires that connect the cockpit to the rest of the aircraft. Some of these are used to carry information from data sensors or microphones to the flight recorders located at the rear of the aircraft.

In flight, these pathways are virtually inaccessible. On the ground, a determined attacker could infiltrate the aircraft and tamper with them. This requires breach of physical security and extensive knowledge about the design of the aircraft.

Any attack on the information pathways, whether in flight or on the ground, would have to be carried out by a very determined attacker. It is likely that attacking these pathways would affect many other aircraft systems, including fuel lines, hydraulic lines and flight control cables. The effect of such an attack carries a high probability that it would disable or destroy the aircraft. Doing this when the attacker only means to disrupt forensic flight data seems quite unlikely.

The pathways between sensors and recorders are not tested except when the system is certified or re-certified. Most flight recorder systems do not report missing or corrupted sensor inputs.

If the recorder itself is not working, the crew is made aware of this condition. Either the FDR or the CVR may be malfunctioning, but if both are not available the flight may not be dispatched.

Because of the inaccessibility of the information pathways between the sensor and microphone sources and the flight recorders, there are essentially no issues of confidentiality, integrity, authenticity and availability of the information on these pathways.

4. Flight Recorders

The flight recorders are located in a compartment located at the rear of the aircraft. Direct physical tampering with them while in flight is virtually impossible. On the ground, tampering with the recorders requires breach of physical security and extensive knowledge of the design of the aircraft.

Physical tampering or destruction of flight recorders seems very unlikely. By definition, the recorders are designed to withstand the forces of an air crash. However, tampering with the electrical connections while leaving the recorders themselves intact is a possibility. This also seems unlikely. If the recorder is disconnected prior to flight, it will not report ready status to the flight crew and the flight will not depart. Altering the connection so the recorder reports ready yet the data does not properly enter the recorder is a theoretical but remote possibility. The gain to the attacker is so insignificant that the probability of this sort of attack on the system is low.

Because of the inaccessibility of the flight data recorders and their hardened cases, there are essentially no issues of confidentiality, integrity, authenticity, availability, likelihood of spoofing or man-in-the-middle attacks associated with the recorders.

5. Flight Data Collection Computer

The flight data collection computer would collect and process flight data and cockpit voice before sending it to the radios to be transmitted. This computer is proposed as part of the design of the Real-Time Flight Data Transmission System and does not currently exist. The computer would probably be physically located in the avionics bay, which is usually near the cockpit at the front of the aircraft. Data on its way to the flight recorders at the rear of the aircraft would have to be channeled not only to the flight recorders but also to the flight data collection computer.

The avionics bay may or may not be accessible while the aircraft is in flight. This depends on the type of aircraft (e.g. B747, B767/757, A320, EMB-120). In flight, an attacker with physical control of the aircraft may have access to the avionics bay. On the ground, access to the avionics bay by an attacker requires breach of physical security and extensive knowledge about the aircraft design.

Because of the inaccessibility of the flight data collection computer, there are essentially no issues of confidentiality, integrity, authenticity and availability associated with it.

6. Pathway Between Flight Data Collection Computer And Radios

The proposed flight data collection computer and the existing radios are located in the avionics bay. The pathway between the computer and the radios is also contained in the avionics bay and does not travel the length of the aircraft, as do the pathways to the aft-located flight recorders.

As described in the previous section, access to the avionics bay is difficult or impossible. Because of the inaccessibility of the avionics bay, there are essentially no issues of confidentiality, integrity, authenticity or availability associated with the pathway between the flight data collection computer and the radios.

7. Software

The Flight Data Collection Computer (FDDC) and Transmission Control Computer (TCC) have software that potentially could be subject to attack. In-flight, there is essentially no vulnerability to attack because of the physical isolation of the computers from the passenger and crew areas. On the ground, however, unauthorized access could occur if an attacker breaches physical security.

8. Radios

Radios used to transmit real-time flight data are located in the avionics bay. As described in the previous two sections, access to the avionics bay is difficult or impossible. Because of the inaccessibility of the avionics bay, there are essentially no issues of confidentiality, integrity, authenticity or availability associated with the radios that transmit real-time flight data.

9. Antenna Systems

The antennae associated with the radio systems are mounted on the exterior of the aircraft. These are inaccessible while in flight, but while the aircraft is on the ground they could be subject to tampering relatively easily. This would adversely affect the availability of the data and could affect the integrity of the data. There are no issues of confidentiality or authenticity of the data arising from attacks on the antenna systems.

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IV. DATA NETWORK

A. INTRODUCTION

The data network associated with the real-time transmission flight data recording system moves data from radio feeds emanating from aircraft in flight to a computer system on the ground that receives and records the data. In this chapter, the design of the proposed data network is discussed as well as the security of the information flowing on the network. The security focus is upon the basic Information Assurance issues of *confidentiality*, *integrity*, *availability* and *authenticity*.

Aircraft in flight are somewhat analogous to cell phones. The aircraft changes its position as it moves along its route of flight just as a cell phone changes its position when its user walks or rides in a car. Like a cell phone, an aircraft is a mobile device that seeks to transmit information away from itself and it must receive information from the ground to maintain secure communication.

Communication issues found in cellular telephone technology are also present in a Real-Time Flight Data Transmission System. Cell phones must switch between cell sites just as an aircraft must switch from one ground station to another as it moves along its route of flight. Additionally, the Real-Time Flight Data Transmission System has the requirement to establish a secure, authenticated session between the ground and the aircraft, and maintain the secure communication session during the switch.

B. MAJOR FEATURES OF THE DATA NETWORK

This section presents the major components of a proposed design of the data network used to move flight data from the aircraft to the data warehouse. Figure 9 presents a functional diagram of the data network.

DATA NETWORK — FUNCTIONAL DIAGRAM

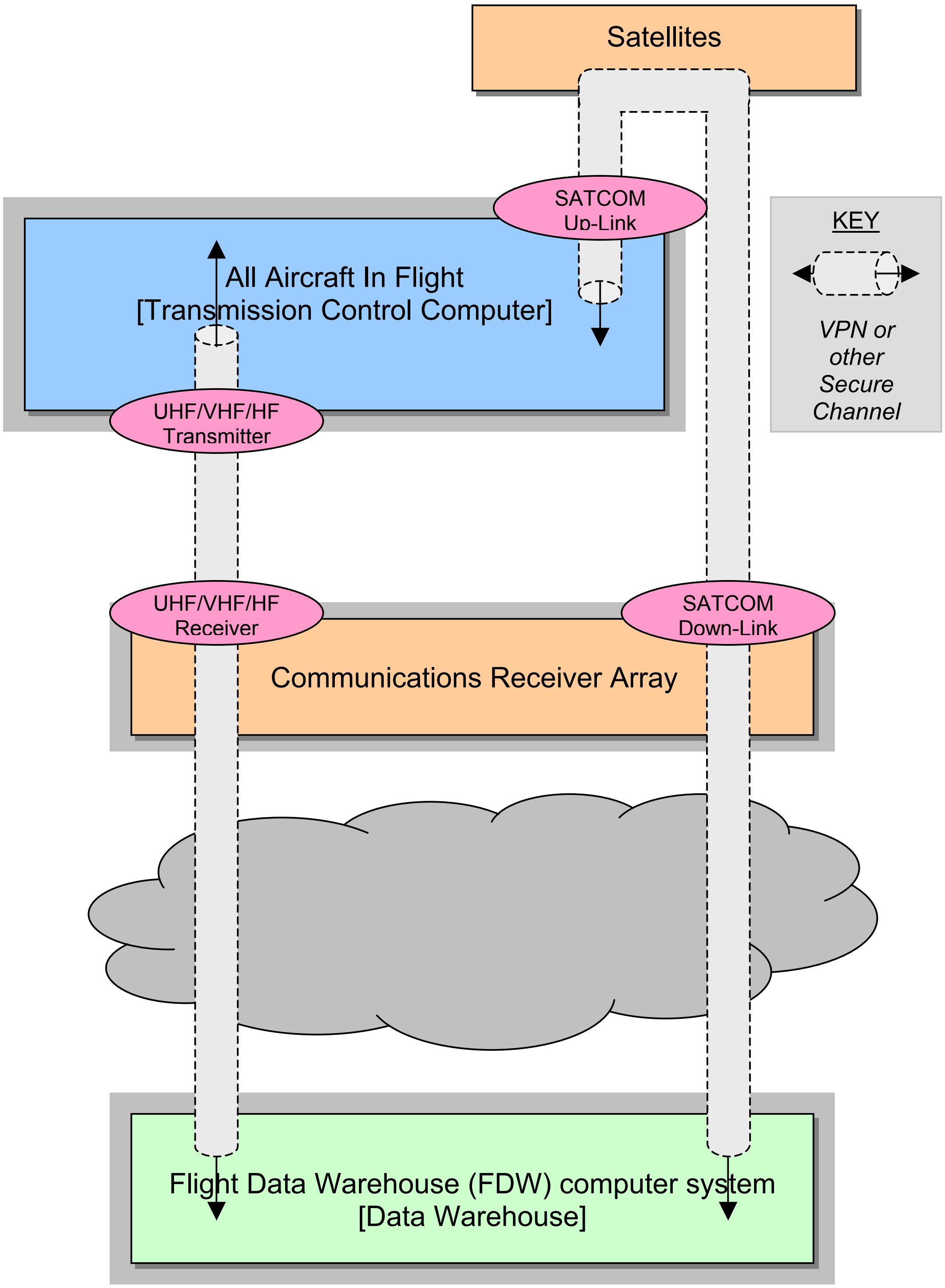

Figure 9. Functional Diagram: Data Network

1. All Aircraft In Flight

Aircraft flying above the surface of the earth and those beginning and ending their flight whilst taxiing on the surface of an aerodrome provide the input into the Real-Time Flight Data Transmission System.

a) Transmission Control Computer

Aboard each aircraft, it is proposed that a *Transmission Control Computer* (TCC) be a computer system dedicated to the management of the communications process used to transmit data off the aircraft.

The functions performed by the Transmission Control Computer include the following.

- Receipt of data from the Flight Data Collection Computer (*see section III.F.5*).
- Selection and management of the transmission medium (*see sections III.A-C*) to use for broadcast of the data.
- Routing of flight data to the radio systems for transmission.
- Serve as endpoint for the secure communications channel with the Flight Data Warehouse (FDW) computer system.

2. Satellites

Communications satellites are a part of the data network used by SATCOM systems. The secure, two-way communications channel between the Flight Data Warehouse (FDW) computer system (*see Chapter V*) and the aircraft passes through a channel between the aircraft and a satellite, from the satellite to a ground receiver that is part of the Communications Receiver Array (*see below*), and from the ground receiver to the FDW via the Internet.

3. Communications Receiver Array

A radio system that is part of the Communication Receiver Array receives the flight data over the transmission medium in use (UHF, VHF, HF, Radar, SATCOM) and passes the data on to the Data Network (Internet).

4. Data Network (Internet)

The Data Network routes the data to the Flight Data Warehouse (*see below*).

5. Flight Data Warehouse

The Flight Data Warehouse (FDW) computer system (*see Chapter V*) receives and stores flight data from the Data Network (Internet). The FDW serves as the endpoint for the VPN or secure channel from the aircraft.

C. COMMUNICATIONS ISSUES

This section discusses some issues surrounding the communication of data off the aircraft. These issues affect the implementation of a secure communications channel from the aircraft to the Flight Data Warehouse (FDW) computer system.

1. Secure Communications Channel

To protect the integrity and confidentiality of the information flowing along it, the communications channel must be secured. To accomplish this, a Virtual Private Network (VPN) is suggested. Following is a brief discussion of VPNs [Ref: B01,S04].

A VPN is a secure "tunnel" traversing the Internet through which encrypted traffic flows from a secured source computer to a secured destination computer.

A VPN has gateways on both the source and destination ends of the tunnel that are the endpoints of the encrypted channel. The source and destination computer networks can be considered logically part of the same network even though they are physically located far away from each other. Computers on both ends of the VPN tunnel send packets to computers on the other end of the VPN tunnel as if they were on the same local area network.

Figure 10 shows the functional components of a virtual private network.

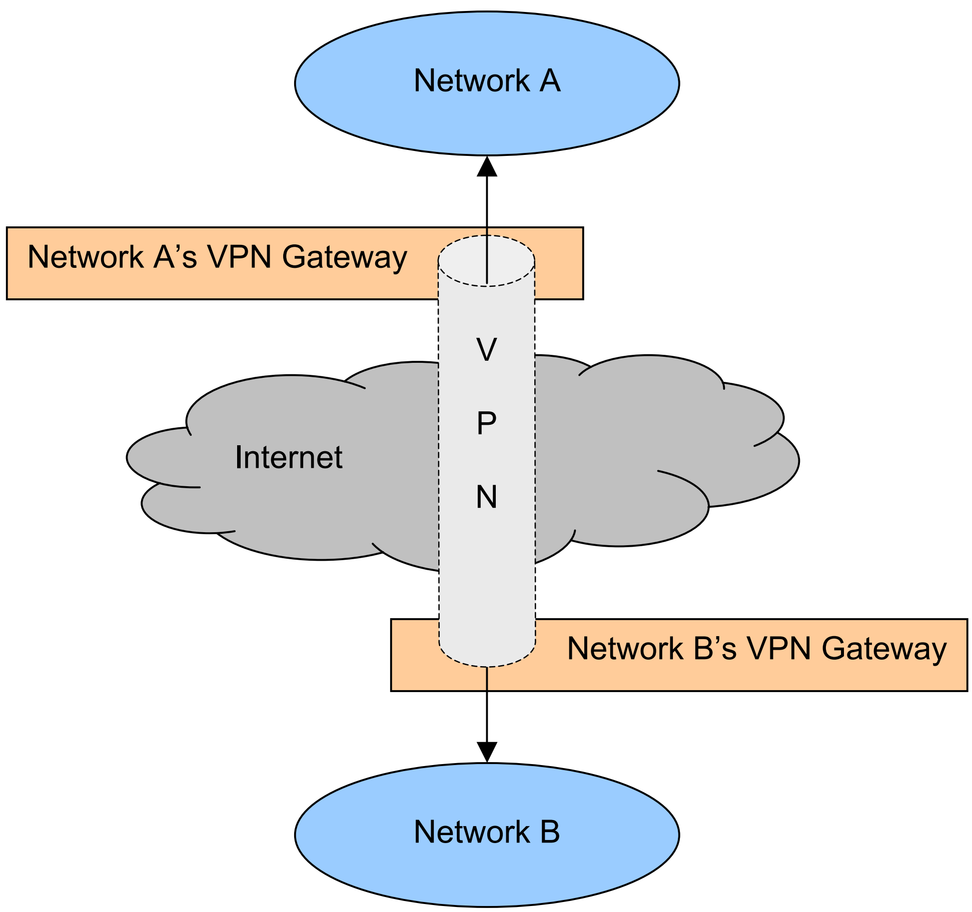

Figure 10. Virtual Private Network (VPN)

The sender's VPN gateway encrypts each packet as it enters the VPN tunnel, including the source and destination IP addresses and the data within it. This encrypted packet becomes the data inside another packet, which carries a source IP address of the sender's VPN gateway and a destination IP address of the receiver's VPN gateway. Therefore, as the packet traverses the insecure Internet, an attacker only sees the IP addresses of the VPN gateways and some encrypted data, thus keeping everything about the true source and destination computers completely hidden.

To build a VPN connection, the two ends communicate their identity to each other using public key cryptography. Each end authenticates to the other by encrypting its identification using the other end's public key. The receiving end decrypts the identification using its private key, which is a closely held secret and the only key that will decrypt the message sent to it by the other end. Once authentication succeeds, a secure trusted path exists between the two ends based on public key cryptography.

Because public key cryptography involves a relatively slow computation, in the interest of better performance the two ends use the trusted path they have established between them to exchange a shared crypto key, called a session key. A relatively fast encryption algorithm uses the session key for subsequent VPN communications.

VPNs are implemented using IPsec, which adds encryption to TCP/IP at layer 2.

2. Aircraft IP Address

To access the Internet for data transmission, each aircraft must have an IP address. This is a unique computer address that the Internet uses in much the same way that the telephone system uses a telephone number.

The Transmission Control Computer (TCC) on board each aircraft receives its IP address using one of two methods described below and uses it to build a secure VPN channel, which serves as a trusted path between the aircraft and the ground.

a) Static IP Address

One method of assigning an IP address to the aircraft is by giving it a permanent (static) address when the airborne components of the Real-Time Flight Data Collection System are installed on board the aircraft. To implement this method of IP address assignment, there would need to be an IP address assigning authority, perhaps the FAA, that has a pool of available IP addresses and assigns one to an aircraft when its RTFDCS equipment is installed. That particular aircraft would then "own" that IP address throughout its lifetime and use it to transmit every packet of data originating from the aircraft.

As relates to the Real-Time Flight Data Collection System, the process of using a static IP address is as follows. First, the proposed TCC aboard the aircraft selects and opens a radio frequency with a remote communications receiver that is connected to the Internet. This is analogous to a desktop computer attaching a network cable to a nearby network jack. Second, the TCC uses the radio communications channel and its previously assigned static IP address to initiate a secure (VPN) communications channel with the Flight Data Warehouse (FDW) computer system.

b) Dynamically Assigned IP Address

A second method of assigning an IP address is to use Dynamic Host Control Protocol (DHCP), which is the standard method used to dynamically assign IP addresses to computer systems attaching to the Internet. DHCP involves a process in which the computer needing an IP address communicates with a DHCP server and requests an IP address. The server pulls from a pool of available IP addresses and assigns one to the computer requesting it. When the computer using the dynamically assigned IP address no longer needs it, such as when it terminates its connection with the Internet or it disappears from the Internet with an open connection that is not used for some period of time, the DHCP server reclaims the IP address and can reassign it to another computer that connects to the Internet at a later time.

As relates to the Real-Time Flight Data Collection System, the process of receiving and using a dynamically assigned IP address is as follows. First, the proposed TCC aboard the aircraft selects and opens a radio frequency with a remote communications receiver that is connected to the Internet. This is analogous to a desktop computer attaching a network cable to a nearby network jack. All that is known is that the computer has attached to the network, but not "who" that computer is. Second, the TCC uses the radio frequency to communicate with a DHCP server on the Internet to request a dynamically assigned IP address. The DHCP server responds with an IP address that is used by the TCC for further communication during that communications session.

3. Unique Aircraft I.D.

All data transmitted from a particular aircraft must have some unique identification associated with it. In the event of a catastrophe involving the aircraft, there must be a way to retrieve all data associated with that aircraft — or at least from the accident flight — from the Flight Data Warehouse (FDW) computer system.

There are three pieces of information that might be used to uniquely identify data originating from a particular aircraft. They are:

- The Media Access Control (MAC) address of the communications Transmission Control Computer (TCC) hardware on board the aircraft
- The aircraft's static IP address (if one is assigned)
- Some unique aircraft identifier that is assigned or associated with the aircraft

The MAC address and static IP address do not change. If used, each would have to be registered with some authority that maps the MAC or static IP address to a particular aircraft, so that if the aircraft is ever involved in an accident requiring access to its flight data, the address could be used to retrieve the data. In this case, some other unique aircraft identifier is not necessary.

If a dynamically assigned IP address is used and the MAC address is not chosen as the unique aircraft ID, then some unique aircraft identifier must be used to identify the data emanating from the aircraft. This might be a combination of the date, flight number, route segment, operator's name, etc.

An advantage of using the MAC address or static IP address is that each is well known and assigned to the aircraft before it joins the Real-Time Flight Data Transmission System. No other unique ID would need to be generated. Upon receipt of communication, the Flight Data Warehouse (FDW) computer system would need to be informed of the MAC or IP address of the incoming data. The MAC address is stripped off at OSI Layer 2 and the IP address is stripped off at OSI Layer 3, so neither is available to the data warehouse application without including it in the information carried by the packet. Using the MAC address, which is 24-bits in length, this theoretically allows for 2^{24} (16,777,216) unique identifiers. Using the IP address, which is 32-bits in length, this theoretically allows for 2^{32} (4,294,967,296) unique identifiers.

a) I.D. Spoofing

Any of the identifiers (MAC address, IP address or Unique Aircraft ID) could theoretically be spoofed, leading to false communication with the Flight Data Warehouse (FDW) computer system in which false data could be given to the system. However, the crypto certificates associated with the PKI key pairs that are used to form the secure communications channel (VPN), are digitally signed by the CA's private key. This private key would also have to be spoofed in order to subvert the VPN carrying the data, which is impossible or at least very unlikely.

If a flight were hijacked and false data were to be injected into the RTFDTS in place of the actual data emanating from the aircraft, then the movements and circumstances aboard the hijacked aircraft might be hidden from investigators. Such an attack would require a high degree of technical sophistication, including generating or having the false data available for injection into the system and subversion of the secure channel between the aircraft and the ground or establishment of a false channel.

It is worth noting that the flight data recorders on board the aircraft would still be active, too, so either the circumstances of the event would have to be such that the recorders were made unavailable to investigators or data recorded by them would have to be subverted as well.

It seems unlikely that an attacker would see the need to go to these extraordinary lengths to carry out an attack. ID spoofing, therefore, while possible, is probably not of great concern with respect to the RTFDTS.

D. INFORMATION ASSURANCE ISSUES

This section discusses some of the information assurance issues associated with data traveling through the data network from an aircraft to the Flight Data Warehouse (FDW) computer system.

1. Confidentiality

Confidentiality of the transmitted flight data means that only the intended recipient of the data is able to understand it. The encrypted Virtual Private Network (VPN) data channel ensures confidentiality of flight data in transit across the data network.

As packets arrive at the receiver's VPN gateway they are decrypted. Unless the flight data carried in the packets is encrypted on the aircraft before it is transmitted, it will no longer be encrypted as it traverses the Flight Data Warehouse (FDW) computer system. Chapter V discusses ways to securely store flight data in the FDW to maintain its confidentiality.

2. Integrity

Integrity of transmitted flight data means that what is received is actually what was sent.

Using a VPN channel gives integrity on a packet-by-packet basis through the strength of the VPN's cryptography. The receiving VPN gateway decrypts each packet it receives through the VPN, giving the actual packet that was sent from the source. It is only able to deliver this packet to the intended destination after successful decryption of the received VPN packet that contained it. If the packet cannot be successfully decrypted, perhaps it was altered or attacked in transit. In this situation, the packet is discarded. Successful decryption can only occur using the correct key (*session key; see section 1*), which is only known to the VPN gateways.

Ensuring the integrity of each packet isn't necessarily enough. Once all packets containing a logical unit of flight data are received, a further integrity check can be accomplished using a hash of the data.

A hash of any message is the result of some computation performed on the message that reduces the message from its original state to some smaller representation of itself. Hashes are one-way, meaning that while the hash is derived from the original message, the original message cannot be derived from the hash.

The sender hashes the message and transmits the hash value along with the message. The receiver hashes the received message generating a second hash value. The receiver compares the two hash values. If they are the same, assuming the sender's hash value was not altered, then the received message is actually what was sent.

To ensure the sender's hash value is not altered, the sender encrypts the hash value before it is transmitted along with the data it represents. With respect to the Real-Time Flight Data Transmission System, the key used for this purpose should be the sender's private key. Later, should it become necessary to verify the integrity of the data, the sender's public key can be used to decrypt the hash generated by the originator of the hash, which was the aircraft that transmitted the hash and the associated flight data.

3. Authenticity

Authenticity is the property of information that assures the receiver that the data was actually sent by the source believed to have sent it.

Receiving data through a secure, public key cryptography-based VPN communications channel assures the data is authentic at the moment it is received by the Flight Data Warehouse (FDW) computer system. The VPN guarantees authenticity of the data traversing it by the nature of the connection. The VPN tunnel is constructed using public key/private key pairs. The keys are obtained from a valid Certificate Authority (CA) using a mechanism signed by the CA's private key. Once the connection is established, a session key is exchanged behind the encryption of the public/private keys. The session key is then used to encrypt the channel. All data successfully passing through the receiver's VPN gateway is therefore authentic, at least as far as being able to say that it originated from the particular aircraft that authenticated itself at the other end of the VPN channel.

Please see Chapter V for a discussion of the assurance of flight data authenticity when it is retrieved from the database.

4. Availability

Because the Real-Time Flight Data Transmission System is based upon a network of radio transmission media of different types, and some of these media are susceptible to radio interference or jamming, availability could be compromised either naturally or by a malicious attacker.

The best assurance of availability is to employ top quality radio equipment, develop a reliable frequency-switching algorithm, and build a network of redundant receivers that provides adequate signal coverage over a wide geographic area.

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V. GROUND CAPTURE AND STORAGE

A. INTRODUCTION

This section describes the ground capture and storage components of the Real-Time Flight Data Transmission System (RTFDTS). Figure 11 shows the overall design for this part of the Real-Time Flight Data Transmission System.

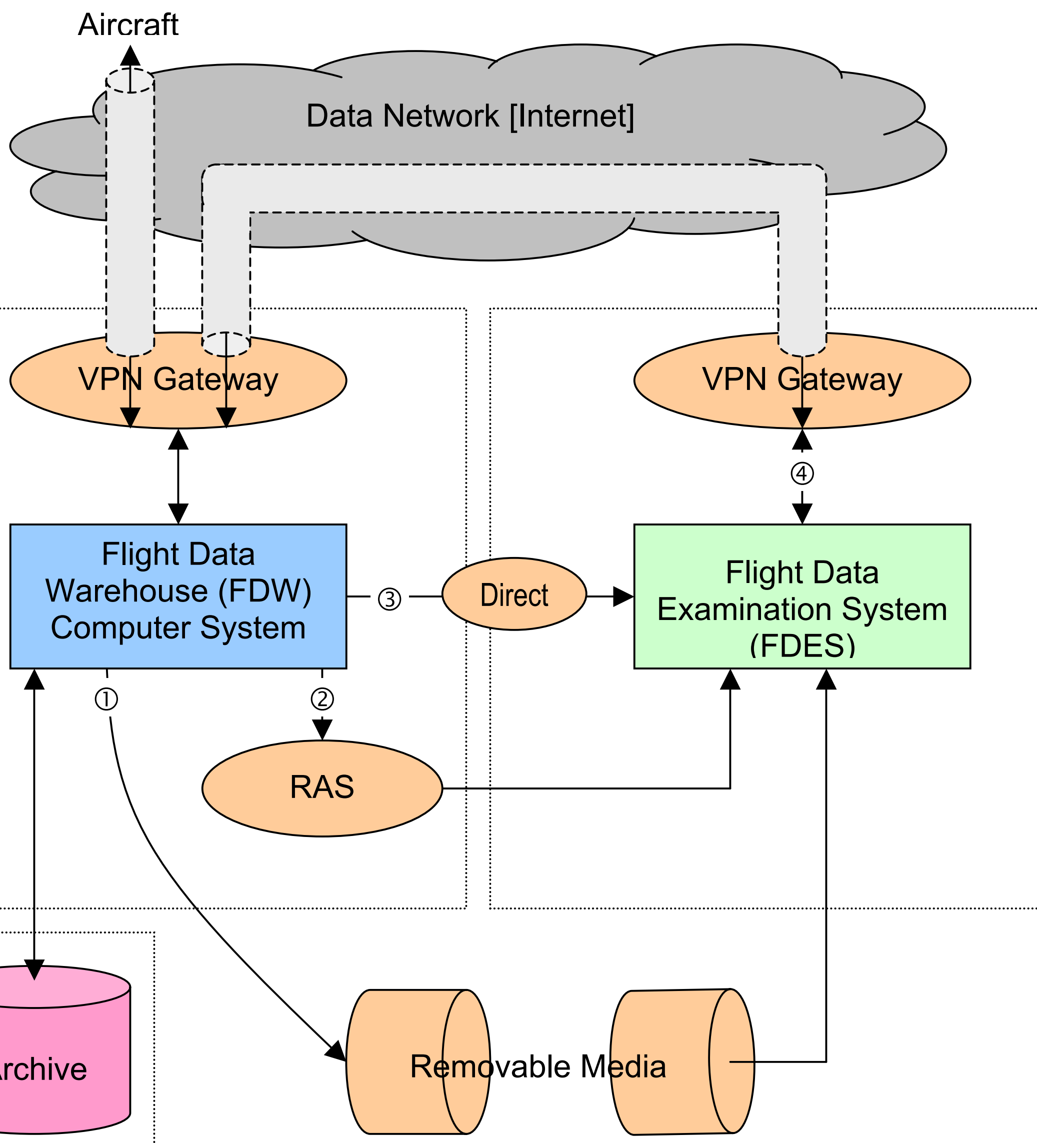

Figure 11. Ground Capture And Storage Overall Design

Following transmission of flight data from the aircraft through the data network, a computer system on the ground captures the data in a data warehouse. This proposed component of the Real-Time Flight Data Transmission System is herein referred to as the Flight Data Warehouse (FDW) computer system.

The FDW handles secure storage and archival of flight data. It allows access to the data only by the originator of the data (aircraft operator) or to the National Transportation Safety Board (NTSB) in cases where NTSB Regulation 830 in combination with applicable Federal Air Regulations (FAR Parts 91, 135, 121) or military directive requires its release.

Great care is placed on assuring confidentiality and integrity of the data as it is in transit across the data network. In order to assure the continued confidentiality and integrity of the data, storage and access to stored flight data requires a similar degree of care.

B. SECURE COMMUNICATIONS CHANNEL (VPN) GATEWAY

1. Flight Data Warehouse Gateway

The termination of the secure data channel between the FDW and the aircraft in flight is the secure communications channel (VPN) gateway. Flight data arrives from the aircraft at this point through an encrypted data channel. It is routed via an internal network or data path to the Flight Data Warehouse (FDW) computer system for processing and storage.

The gateway also serves as the endpoint of a secure data channel between the Flight Data Warehouse (FDW) and the Flight Data Examination System (FDES). This channel is used to transfer data from the FDW to the FDES after an air crash. A secure channel is necessary to protect confidentiality of the data as it passes through the insecure data network (Internet).

2. Flight Data Examination System Gateway

The secure data channel (VPN) gateway associated with the Flight Data Examination System (FDES) is the endpoint of the channel between the FDES and the Flight Data Warehouse (FDW) computer system, which is used for transferring flight data pertaining to an accident flight to the NTSB.

C. FLIGHT DATA WAREHOUSE (FDW) COMPUTER SYSTEM

The FDW computer system is the heart of the proposed ground data capture and storage machinery. This computer system receives data that has been transmitted from aircraft in flight through the data network secure data communications channel (VPN). The FDW stores data in a database for retrieval in the aftermath of an air crash by receiving valid requests for information from an NTSB Flight Data Examination System (FDES). Finally, the FDW off-loads "current" data into the data Archive.

1. Storage Rules

The present system of flight recorders includes rules about how long data must be stored before it is discarded or overwritten. A FDR stores 25 hours of flight data and a CVR stores 30 minutes (soon will be two hours) of cockpit voice data. There will be a requirement for similar rules specifying the storage requirements for the Real-Time Flight Data Transmission System.

The 25-hour FDR and 30-minute CVR rules are in place because they mirror how flight recorders have historically worked. Essentially, the recorder can be thought of as a loop of tape of some length — 25 hours or 30 minutes — that is continually overwritten. In fact, before solid-state devices were used, this was the exact nature of foil FDR and magnetic tape CVR devices.

Because of the proposed design of the Real-Time Flight Data Transmission System, flight data can be thought of as blocks of data that encompass an entire flight from start to finish. From the point of view of a computer recording this data, it makes more sense to tie the recording rules to entire flights rather than a certain amount of recorder time.

The FAA will have to examine this change of thinking and issue rule-making to reflect it. It is beyond the scope of this thesis to state what these rules might be, although it might be recommended to keep flight data only as long as a flight is in the air and then discard it once the flight is successfully recovered (has landed safely).

An Archive mechanism is described in this thesis, but the need for this is actually a reflection of the storage rules that are ultimately adopted. If there is no interest in keeping flight data after a flight is successfully recovered, then there is no need for an archive. Or, the Archive might receive flight data from a successfully recovered flight and store it for some specified period of time. Even though the flight landed safely, this data may be very useful if the aircraft is lost on the next flight.

2. Storage Methods

Presently, flight data is recorded in on-board flight recorders. The data is physically confined to devices aboard the aircraft that recorded it, resulting in relatively good assurance that the data will remain private.

The issue of confidentiality to ensure privacy has been addressed throughout the sensor data acquisition and data transmission portions of the proposed Real-Time Flight Data Transmission System. Now that the data has arrived on the ground and is to be stored in the FDW, the requirement is strong to restrict access to the flight data only to its owner (the flight's operator) or, in the aftermath of an air crash, to the NTSB.

Two methods of assuring privacy are proposed. They are MLS and encrypted data storage.

a) Multi-Level Security (MLS) Design

Multi-Level Security is usually used in environments such as the Department of Defense (DoD) where there is a need to separate Top Secret, Secret, Confidential and Unclassified data. A feature of the DoD classification system is that these classifications are further divided into compartments. An individual may be cleared to access Top Secret – Special Compartment Information (TS-SCI), but will only have access to certain Top Secret compartments on a need-to-know basis.

An MLS design could be used to address the privacy concerns associated with the FDW. An MLS is attractive for use on a centralized Flight Data Warehouse computer system, since on such a system flight data from many operators would be stored and there would be a need to separate the data into secure compartments.

The attractive feature of MLS is compartments. The model that seems most appropriate to the FDW is to consider each operator a separate compartment, such that only that operator has need-to-know for the data stored in the compartment.

When NTSB notification is required per NTSB Regulation 830, applicable FAR 91/121/135 rules, or military regulations require release of flight data, then the operator would read data in its compartment and forward it on to the NTSB, similar to what the operator does now in the case of data contained in a flight recorder of an accident flight.

This storage design integrates well with data arriving through a Virtual Private Network (VPN). Such data does not need to be encrypted prior to entering the VPN channel to ensure its confidentiality whilst in transit because the secure data channel is encrypted. Data comes out of the VPN exactly as it entered — unencrypted. A label can be attached to the unencrypted data, which as noted earlier would be the identification of the operator that owns the data, and the data can then be stored directly in that form by the MLS storage system. Privacy of the data is assured because of the need-to-know associated with the compartment assigned to the operator of the flight originating the data.

An advantage to using MLS is that there is a minimum of encryption involved in the process, which can be expensive in terms of computing complexity and time. Data is encrypted only once as it is carried by the VPN.

A disadvantage of MLS from the point of view of the operator might be that the data exists in unencrypted form while it is out of the direct control of the operator. This presents the possibility of a perceived security vulnerability that may be of concern to the operator, although if the MLS operating on the FDW does exactly what it is designed to do and nothing more then the data will remain private. It could be that lack of confidence in this process might be perceived as an unacceptable risk for some operators.

b) Encrypted Storage Design

A way to assure the privacy of data stored in a centralized FDW is to store it in encrypted form.

If flight data is encrypted using the operator's public key before it leaves the aircraft, it can only be decrypted later using the operator's private key. The operator would only decrypt stored flight data for its own purposes or in cases where release of crash data to the NTSB is required.

Data generated aboard the aircraft could be encrypted with the operator's public key and then given to the secure data channel (VPN) for transmission to the FDW. When the data emerges from the VPN it is still encrypted with the operator's public key and ready to be stored.

If flight data is not encrypted aboard the aircraft, it emerges from the VPN not encrypted. The FDW would then have to apply the operator's public key prior to storing the data, which means the FDW would have to store the public key of each operator for which it handles data. These public keys would have to be obtained from a trusted Certificate Authority (CA) using a mechanism digitally signed by the CA's public key.

Regardless of where the data is encrypted, double encryption is a part of this storage design. One encryption is conducted either on board the aircraft or by the FDW after the data is received through the VPN. The other encryption is conducted by the VPN as a part of its normal secure operation.

Double encryption consumes more processing power and time than if the data is encrypted only once. It could introduce performance issues. It may be that encrypting data aboard the aircraft is more efficient than tasking a central FDW with encrypting the data prior to storage, or such encryption on board the aircraft is too time and processor consuming and must be done on the ground. This issue will require further investigation and is beyond the scope of this thesis.

3. Archive Data

As noted previously, the need for Archive is a result of the rules that are established by the FAA for flight data handled by the Real-Time Flight Data Transmission System. In the event such rules include Archive, this discussion is presented.

Figure 11 shows the overall design of the ground capture and collection portion of the RTFDTS. The Archive is shown as being fed from the FDW via a direct connection. However, the Archive may not be co-located with the FDW and instead is accessed via a company local area network or the Internet. In this case, the connection between the FDW and the Archive might include a VPN.

When it is determined flight data is to be archived, the FDW sends the data to the Archive and deletes it from "current" storage held by the FDW. Flight data remains in Archive for the period of time specified by the rules governing such storage.

Archived data could be stored on off-line media or it may be stored in an online database, or it might be passed on to the operator for disposition in accordance with the operator's rules, or FAA and NTSB's regulatory requirements.

D. FLIGHT DATA EXAMINATION SYSTEM (FDES)

This proposed part of the Real-Time Flight Data Transmission System is used when the need to examine flight data exists after a crash. The NTSB would own and operate a single FDES or multiple FDES systems. The essential function of the FDES is to receive flight data from a Flight Data Warehouse (FDW) computer system. Exactly what the FDES does with the data from that point is beyond the scope of this thesis. It might forward it on to other NTSB systems or perform some kind of processing of the flight data.

Figure 11 shows four suggested methods of transferring data from the FDW and/or Archive to the FDES. The paragraph numbers following (1, 2, 3, 4) correspond to the numbers ①, ②, ③ and ④ on figure 11.

1. Removable Media

The FDW could copy flight data to a removable medium, such as a floppy disk, removable hard disk, USB "thumb drive", punched paper tape, disk pack, magnetic tape, etc. This would then be physically transported to the FDES and loaded onto the FDES for processing.

2. Dial-In Remote Access System (RAS)

Without using the Internet, the FDES could use either a dial-in or dedicated (a.k.a. "leased") line to access the FDW. Such lines can be encrypted to address confidentiality.

3. Direct Connection

If the FDES is co-located with the FDW, the FDES could access the FDW directly through a direct connection. In this case, it would not be necessary to encrypt the connection on the assumption that the entire computer system is physically secured.

4. Secure Communications Channel (VPN)

If the FDES accesses the FDW through the Internet, it could do so through a secure data channel (VPN). This provides a secure, encrypted channel through which unencrypted flight data can securely pass through the un-trusted Internet environment.

E. CENTRALIZED VERSUS DISTRIBUTED

The components of the ground capture system could be either centralized or distributed. There could be one large Flight Data Warehouse (FDW) computer system, one Flight Data Examination System (FDES) and one Archive. Or, each of these components could be duplicated any number of times and distributed over a wide area.

1. Centralized

If there is one Flight Data Warehouse (FDW) computer system, one Flight Data Examination System (FDES) and one Archive, there are a number of issues to consider pertaining to this design.

Concept — This design requires that some entity, perhaps the FAA, maintain one large FDW in which all flight data is stored. When the NTSB has the need to access the data, it has one source to which it would go to retrieve it.

Cost — The question is *who pays for the storage computer?* Data from all operators would be stored on one computer system. The government, aircraft operators, or a combination of the two might fund the system.

Control — The question is *who has control of the data stored in the computer system?* The operator of the flight owns the data, but another entity would provide and maintain the computer that stores it.

The data must remain private to the operator until such time as it is required to be released by regulation in response to an accident.

A multi-level security (MLS) system would address the requirement for privacy as would storing the flight data encrypted with the operator's public key.

All The Eggs Are In One Basket — One central data warehouse system exposes the RTFDTS to possible loss of service should the system suddenly become unavailable for any reason. For fault tolerance, a backup system should be considered along with complete measures to guard against single system loss of service.

2. Distributed

If there are several Flight Data Warehouse (FDW) computer systems, Flight Data Examination Systems (FDES), and Archive locations, the associated design and operation issues are different from those related to a single, large data warehouse computer.

Concept — This distribution of assets allows individual operators to own and operate their own FDW, or a series of FDW systems, in a manner and at locations of their choosing. When the NTSB has the need to access the data, it would have to request the information from the operator, who would then inform the NTSB of the specific FDW to which it must connect to retrieve the data.

Cost — Cost would be distributed among the operators. This is similar to the concept of each operator equipping its fleet of aircraft with flight recorders. Perhaps the operator would not bear the entire cost of purchasing and maintaining the systems if government were willing to provide some form of subsidy or other assistance.

Control — If each operator has its own FDW or series of FDW's, the operator would have absolute control of its flight data as it does now with data stored in flight recorders. Access to the data would be easy to control and provide to the NTSB after a crash. Techniques to ensure fault tolerance would be required for each local system, such as multiple redundant systems, mirrored disk drives and sound backup policy.

F. INFORMATION ASSURANCE ISSUES

This section discusses or summarizes the information assurance issues associated with storage of flight data within the Flight Data Warehouse (FDW) computer system.

1. Confidentiality

Confidentiality is addressed through the use of either a MLS storage design or an encrypted data storage design.

a) MLS Storage Design

Using compartments within an MLS storage system assures confidentiality of the data. An MLS design lends itself to storing data in an unencrypted form, but this brings into question the data before it is compartmentalized. The data would probably be handled by the FDW in unencrypted form before it is compartmentalized, which results in a concern for its privacy should the FDW not handle the data correctly. There is also the possibility of a disclosure attack as the data is handled before being compartmentalized, although a high assurance system with trusted mechanisms for compartmentalizing data could address this concern.

b) Encrypted Storage Design

Reliance upon public key cryptography is used to assure confidentiality of stored data. This is a good assumption if the encryption algorithm is sufficiently robust, such as is the case with 3DES or AES. Only the operator can decrypt the data because only the operator possesses the private key that corresponds with the public key used to encrypt the data.

Using the encrypted storage design, flight data never exists in unencrypted form while out of the direct control of the operator, which should give operators good assurance of the confidentiality and privacy of their data.

The operator should never release its private key. When it is required for the decryption of flight data stored within the FDW and/or Archive, the operator must interact with the FDW system in a secure manner. This could be done using smart cards or other mechanisms designed to make use of the operator's private key for decryption. Alternatively, if the FDW is not owned and operated by the operator, data might be routed from the FDW to the operator, decrypted by the operator using its private key, then sent on to the FDES for processing.

Encrypted flight data stored in the FDW and Archive databases would need to be stored along with an unencrypted identifier. The identifier should consist of that which is necessary to identify a particular flight. For example, it could be a combination of operator ID, date and flight number. To ensure integrity, the identifier might be bound to the encrypted data using a crypto seal.

2. Integrity

Integrity of stored data means that when retrieved, there is assurance that the data is as it was originally stored. Reliance upon the underlying operating system of the FDW and Archive systems provides sufficient assurance of this property.

To enhance integrity assurance, data could be hashed and the hash stored along with the data. When retrieved, the data would be re-hashed and the stored hash compared with the new hash. If they are equal, the data is as it was stored and integrity is assured. If they are not equal, there is an error somewhere in the process and integrity is not assured. Because the FDW has system access security, it is probably not necessary to encrypt this hash. System Access Security is meant to include all the measures employed to secure the computer system, such as including a guard at the gate to the facility housing the system, a cipher lock on the door to the computer room, the user name and password combination required to log on to the system, and anything else that contributes to the security of the system.

3. Authenticity

Authenticity is the property of data that means the receiver of the data is assured that the data actually originated from the source it is believed to have originated from. When examining crash data, the NTSB needs the assurance that the data with which they are working actually originated on the accident flight.

Flight data consists of two parts. The first part is data identification information, such as the identity of the operator, the aircraft number, the flight number, the date, and so on. The second part is the data itself.

When flight data arrives at the FDW and is stored in the flight database, it has already passed through various assurance mechanisms such that at that moment it is known to be authentic (*see chapter IV.D.3*). The flight data and its accompanying identifying information are stored in the flight database by the FDW. The FDW should be a secure computer system with access control such that information in the database cannot be maliciously altered.

Because the data was authentic when it was stored and the database is secure, if the data along with its identifying information were later given to a Flight Data Examination System (FDES) for processing after an accident, the NTSB would be assured that the data is authentic.

4. Availability

There are two availability issues associated with the FDW.

a) Receiver

First, the system must be available to act as a receiver. There would never be a time when flights would not be in the air transmitting flight data. Therefore, the FDW must always be available to receive and record the data. Measures should be taken to assure this, such as using backup power sources, multiple locations and multiple FDW's, and Archive located remotely from the FDW.

b) Post-Crash Availability

Second, flight data must be available to crash investigators following an air crash. The necessity to have instant access to stored flight data might be questioned if one considers the present system. Presently, it may take days to locate the flight recorders and this seems to be acceptable to the NTSB. Although it is certainly best to have all flight data available immediately following a crash, it is probably not absolutely necessary. But, reliable and complete storage of all data associated with a flight should be assured to provide access to flight data within a reasonable time following a crash.

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VI. PRACTICAL AVIATION CONCERNS

A. INTRODUCTION

The Real-Time Flight Data Transmission System is an idea that exists to serve the air safety interests of the flying public, the aviation community, and to promote flight safety by enhancing the effectiveness of air crash investigation.

It is a large, complex system that handles a great quantity of information. The aviation world is even larger and more complex.

The Real-Time Flight Data Transmission System must fit into the complex world of aviation in a practical way. It is useful to acknowledge some of the practical aviation concerns pertaining to such a system.

This chapter discusses some of the practical concerns about the system.

B. FAIR USE, PRIVACY AND NATIONAL SECURITY

This section discusses some of the concerns of fair use, privacy and national security as they relate to the Real-Time Flight Data Transmission System.

1. Fair Use

The very existence of flight data begs the question, "How should we use this information?" The essence of crash investigation is to determine the probable cause of the crash and to use this knowledge to help prevent similar disasters in the future.

Discovering that a certain part is at fault is useful — for example, the elevator jackscrew malfunctioned on Alaska flight 261 and caused the aircraft to crash into the Pacific Ocean. We need to know this to better the design and maintain jackscrews, so they don't cause future crashes. But, the maker of the part and the maintenance personnel who are charged with keeping it functioning properly feel the finger of blame pointed at them.

Discovering that the flight crew failed to properly execute some procedure is useful — for example, the flaps were not set to takeoff position in Detroit and a Northwest Airlines flight crashed into a parking lot. We can use this kind of information to improve cockpit checklists and procedures. But, the families of the crew may feel the airline put their loved ones in a situation with defective procedures that allowed competent pilots to make mistakes, and the airline may feel the highly-trained, experienced flight crew failed to properly follow procedures.

Fair use of the crash data is an important and emotionally volatile issue. Crash investigators must properly use the data to make reasonable judgments about probable cause and not maliciously point the finger of blame. Present procedures and policies for handling of crash data respect this concern. Those developed for handling of data by the Real-Time Flight Data Transmission System also must respect this concern.

2. Privacy

At first glance, the availability of flight data that shows precisely what happened leading up to an air crash would seem to be a very good thing for all concerned. But, throughout this thesis the idea of confidentiality is discussed, including a technical description of the means necessary to assure confidentiality at every step along the way. Using means intended to ensure the confidentiality of the flight data handled by the system, the first step toward privacy is achieved: the data is not subject to unwanted disclosure. Privacy continues beyond data confidentiality.

Achieving privacy starts by strictly controlling who has access to crash data. Everyone involved in aviation has privacy concerns — families of crash victims, airlines, manufacturers of parts, labor unions, maintenance personnel and air traffic controllers.

The concern about a real-time transmission system is that flight data instantly acquires greater potential for exposure. Everyone concerned with data privacy should have this concern. With proper design and implementation, the real-time system can be no more exposed than the present system of flight recorders on board the aircraft.

The computers and radios used to transmit the data are analogous to the wires that presently connect sensors to the flight recorders. The FDW is analogous to flight recorders. Privacy is achieved by implementing methods that assure confidentiality of transmitted flight data, as well as physical security and access control of the data warehouse computers comprising the FDW.

Therefore, by complete and thorough implementation of sound information assurance practices, the aviation community must be convinced the data really is confidential and that effective safeguards are in force to prevent unwanted disclosure of flight data.

3. National Security

One reason governments are in charge of regulating aviation is to protect national security. The events of September 11, 2001, perfectly illustrate this point. To ensure the safety of the rest of the nation, the FAA immediately grounded all flights when the WTC was attacked.

An aircraft involved in a situation with national security implications may produce sensitive or even classified flight data. Information contained in flight data, most notably cockpit voice recordings, could expose sensitive military or other procedures and practices either on board the aircraft or in its operational environment.

Therefore, by complete and thorough implementation of sound information assurance practices, the government must be convinced the data really is confidential and the system will protect national security when the need arises.

C. OLDER AND SMALLER AIRCRAFT

Aviation does not consist entirely of large airline fleets of modern jetliners. There are many operators that fly older and smaller aircraft.

There are technical aviation concerns about adding equipment to certain aircraft. The added weight of a few radios and antennae probably has no adverse impact on the weight-and-balance situation of a Boeing 747, but it may significantly affect a Cessna 402 — an un-pressurized, six- to ten-passenger piston engine twin — such as that used by Pacific Wings, an airline based on Maui that flies Hawaiian inter-island flights.

Space and power are other concerns. There may be no available space in the avionics bay or compartment in which to place the additional equipment. Some older and smaller aircraft are very limited in their capacity to add this type of equipment. Also, there may be inadequate electrical power available to handle the added equipment.

For these reasons and others, it may not be possible to equip older and smaller aircraft with the Real-Time Flight Data Transmission System. This is a point to consider when drafting regulatory changes pertaining to a real-time system.

D. TECHNICAL STANDARD ORDER (TSO) AVIATION EQUIPMENT VERSUS NON-AVIATION COMMERCIAL OFF-THE-SHELF (COTS) PRODUCTS

This section discusses some of the reasons that it is difficult to envision the use of commercial off-the-shelf (COTS) products in building the Real-Time Flight Data Transmission System.

Data communication and computer networking are well known disciplines. There is a wealth of available expertise and equipment that can handle these functions. But, for several reasons this familiar and inexpensive COTS equipment may not be suitable for airborne use.

1. Reliability / TSO

Because reliability of equipment is a different issue in the air than it is on the ground, there has long been a system in aviation for specifying exacting, aviation-suitable technical specifications for aircraft equipment.

The Technical Standard Order (TSO) is the instrument by which technical aviation standards for equipment are communicated. Equipment meeting TSO specification often requires specialized or at least additional manufacturing work as compared to the same equipment not conforming to the TSO.

Simply certifying that equipment meets the specifications of a certain TSO — even if it is exactly the same as equipment that is not certified to the TSO — involves time and effort on the part of the certifier, and thus added cost.

The bottom line about TSO is that TSO'd equipment is almost always more expensive than non-TSO'd equipment, sometimes significantly more. It may seem attractive to design the Real-Time Flight Data Transmission System using inexpensive COTS products, but in aviation use of this kind of equipment simply does not happen.

2. 400Hz Power

Another reason non-aviation COTS products may not be suitable for the Real-Time Flight Data Transmission System without modification is that many aircraft power systems operate at 400Hz, not at the 50Hz (international standard) or 60Hz (United States) with which we are familiar.

Modifications would be required to allow COTS devices to accept 400Hz power.

E. TESTING AND DEVELOPMENT, CERTIFICATION AND ACCREDITATION, MAINTENANCE

This section describes some of the necessary steps toward implementing the Real-Time Flight Data Transmission System, including *testing and development*, *certification and accreditation (C&A)* and *maintenance*.

1. Testing And Development

NASA has developed and flown a prototype demonstration of a real-time flight data transmission system. Equipment was placed aboard two aircraft — a Boeing 757 and a Learjet 25. The system successfully transmitted flight data from both aircraft in real-time to a ground receiver station. Although it has been dismantled, NASA proved that it is possible to transmit flight data in real-time from an aircraft to the ground [Source: N01].

NASA's test showed the system is possible, but further testing and development is required in various aspects of the system, such as:

- Data link hand-off
- Flight Data Collection Computer (FDCC)
- Transmission Control Computer (TCC)
- Flight Data Warehouse (FDW) computer system
- Data Examination Subsystem (FDES)

2. Certification And Accreditation (C&A)

This section describes two certification and accreditation aspects important to the Real-Time Flight Data Transmission System.

a) NIACAP C&A

As the real-time system is designed and implemented, since all or part of it will undoubtedly be a U. S. Government computer system, it will require formal security certification and accreditation to comply with United States law and Presidential Decision Directives.

Certification and accreditation will follow the National Information Assurance Certification and Accreditation Process (NIACAP) or other similarly applicable program.

The NIACAP is an extensive four-phase process that focuses upon the information assurance aspects of a computer system. Phase one (Definition) involves an initial specification of the security features of the system. Phase two (Verification) involves certification testing and evaluation to verify the design. Phase three (Validation) involves security testing and evaluation to validate the design and official accreditation of the system. Phase four (Post Accreditation) involves post-accreditation tasks and continued maintenance until the next required certification review [Source: N02].

b) FAA Certification

As specified in 14 CFR Parts 91, 121 and 135, flight recorder systems are subject to performance standards and periodic inspection and re-certification. The FAA will need to create regulatory rule changes that incorporate the performance standards and inspection requirements of the real-time transmission system.

3. Minimum Equipment List (MEL) / Dispatch

The Minimum Equipment List (MEL) is a sort of checklist that specifies whether an aircraft may be dispatched when equipment is missing or inoperative, and dispatch restrictions based on inoperative equipment.

The FAA will need to create regulatory rule changes concerning MEL dispatch requirements for the airborne components of the Real-Time Flight Data Transmission System.

The flight dispatcher and captain must both know whether or not the flight may be dispatched if a component of the real-time transmission system is inoperative, and the restrictions that places on the flight operation.

4. Maintenance

The Real-Time Flight Data Transmission System requires maintenance of its components to ensure they operate correctly within specification limits. This includes the airborne components of the system, the radio systems and Internet connections, and the Flight Data Warehouse (FDW) computer system.

Maintenance is an important cost consideration for development and implementation of the real-time transmission system.

F. ENHANCING THE STATE-OF-THE-ART OF CRASH INVESTIGATION

Perhaps the basic question is, "Why should we develop a system to transmit flight data in real time from an aircraft to the ground?" The answer is that this system seeks to improve flight safety by extending the state-of-the-art of air crash investigation.

There is a present state-of-the-art of air crash investigation. It involves extensive resources available to the National Transportation Safety Board, the

Federal Aviation Administration, operators and companies that produce flight recorders. It also involves the sum total of government regulation of the aviation industry by the FAA and NTSB.

Enhancing crash investigation effectiveness and technology can be accomplished in a number of ways, but is the creation of the Real-Time Flight Data Transmission System the way that should be pursued next? Is it the "low hanging fruit" that we should pick?

There are other concerns that appear to be of more immediate concern than this system. For example, the present rule requires recording of 30 minutes of cockpit voice. The NTSB has found that in some cases this is not enough data and important clues to the probable cause of the crash are lost beyond the 30-minute time limit. The FAA and NTSB are working on extending the time required for CVR data from 30 minutes to 2 hours. This is a relatively easy change to make in the state-of-the-art, since virtually all modern digital flight recorders record this much information, yet it has taken several years to make this change because, in large part, of the burden of compliance (financial and otherwise) on the part of the operators [Source: S02,S03].

While the Real-Time Flight Data Transmission System may not be the next step in advancing the art of crash investigation, it is certainly attracting widespread interest in the aviation community. Its design and implementation is worth serious consideration.

G. ECONOMY

The state of the economy has a lot to do with whether there is an implementation of the Real-Time Flight Data Transmission System. Such a system is complex and expensive. Funding must be available for research, design, testing, certification, deployment and continued maintenance.

After the attacks of September 11, 2001, the global airline industry suffered grave financial crisis. It continues to suffer. Airlines failed around the globe, for example the once proud Swissair is no longer with us. With few exceptions — Southwest Airlines is one — the remaining airlines continue to suffer difficult financial times and report losing money quarter after quarter.

The manufacturers of aircraft, such as Boeing Aircraft Company, certainly seek to produce the safest possible products [Source: S02]. The regulators of the industry, such as the Federal Aviation Administration, certainly seek to create rules and practices that promote the highest possible level of safety [Source: S03].

Since there will be a significant financial burden on the airline industry when a real-time flight data transmission system is created, the FAA is proceeding very cautiously on this issue. These may not be the right economic times in which to mandate this particular financial burden upon the industry.

A real-time transmission system could be an optional expense for the industry if a developer were to create such a system without a government mandate requiring it. The developer would do so in the hopes of making a profit selling the system. It is outside the scope of this thesis to make the judgment of whether developing a real-time transmission system is a sound business decision.

The cost of a real-time transmission system could be a mandated expense if the FAA and NTSB decided the system is necessary and went about creating new regulation requiring it. But, the NTSB is not clamoring to replace or extend the present flight recorders because they aren't giving them the information they need. The FAA sees no pressing concern that the system would address and does not want to burden the industry with the added systems and expense [Source: S03].

VII. SUMMARY, CONCLUSIONS AND FUTURE WORK

This chapter provides a summary of the Real-Time Flight Data Transmission System. It summarizes the benefits and overall design of the system, presents conclusions and offers topics for future work.

A. SUMMARY

1. Benefits

A Real-Time Flight Data Transmission System would benefit the aviation community and the general public by enhancing flight safety. It would provide post-crash investigators with flight data more quickly and easily than it is available today and in situations where it would otherwise be unavailable.

Situations in which the information may be unavailable include those when the FDR and/or CVR are severely damaged and data is unusable, or when the flight recorders are irretrievable. Examples include severe and violent crashes featuring extreme forces exceeding design limitations of the recording devices sufficient to destroy them, extremely hot fires, aircraft lost in extremely remote locations such as far out to sea, or airborne recorder failure.

Regardless of the recovery status of the FDR and CVR, the real-time transmission system will enhance post-crash investigation by providing very timely or instant access to flight data.

2. Design

Figure 12 shows a graphical overview of the design of the Real-Time Flight Data Transmission System.

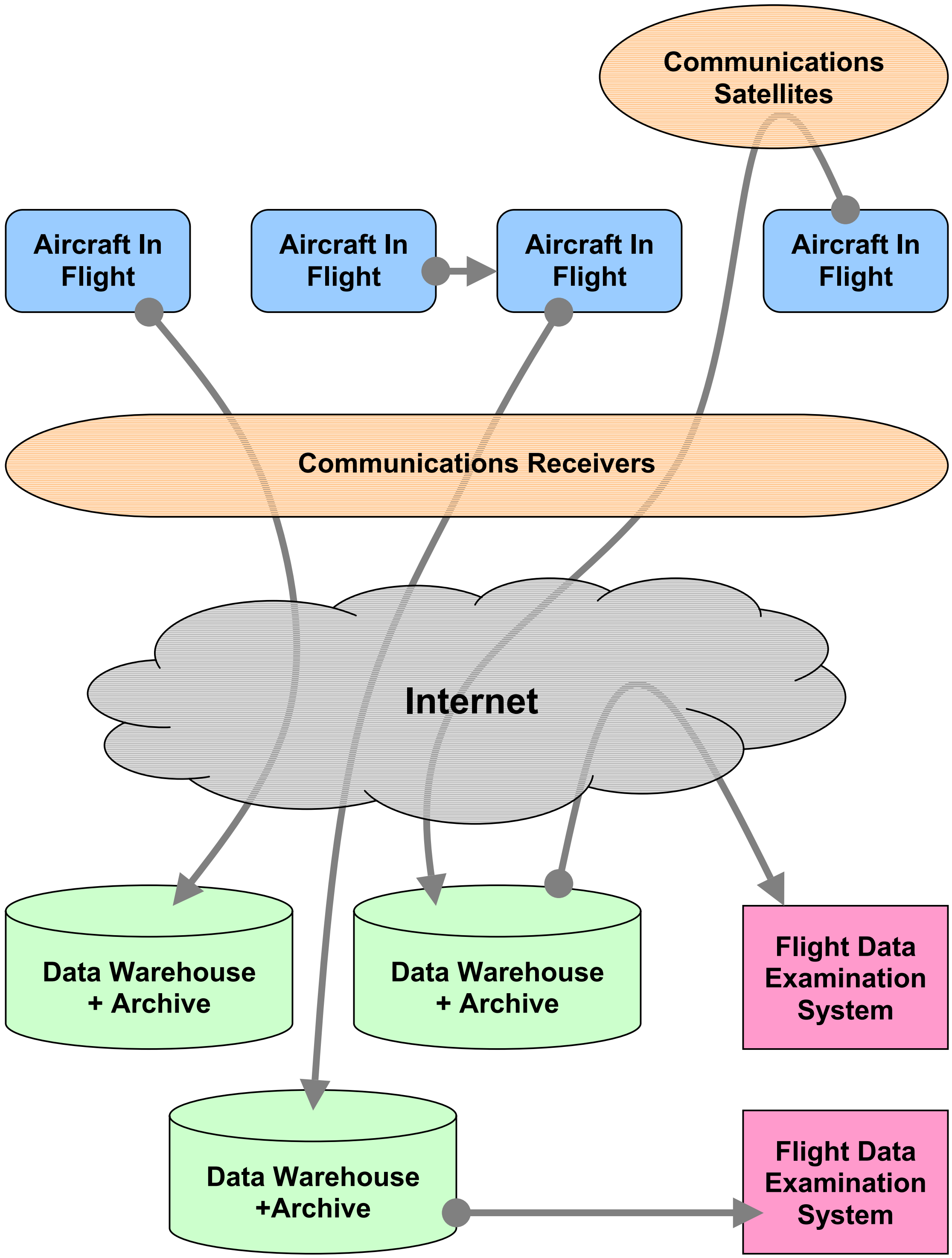

Figure 12. Real-Time Flight Data Transmission System Overall Design

Information flows within the system from the aircraft in flight, through satellites and communications receivers, the Internet, and toward the Data Warehouse + Archive computer systems. Flight Data Examination Systems (FDES) interact with the Flight Data Warehouse (FDW) computer systems after disasters occur to retrieve and process flight data from accident flights.

B. CONCLUSIONS

The purpose of this thesis was to ask and answer the following questions.

- Is it feasible to build a system that has the capability of transmitting flight data in real-time from commercial and military aircraft to a ground recording station?
- What are the technical characteristics of such a system?
- What are the information assurance characteristics of such a system?

1. Feasibility

It is unlikely that the Real-Time Flight Data Transmission System will be implemented any time soon. Perhaps Tim Ridgely of Boeing said it best when he observed, *"I think the characterization that this would be pretty far out on the upper part of the tree, not low hanging fruit, is probably true"* [Ref: S02].

Implementation of the Real-Time Flight Data Transmission System will require development of airborne collection computers, additional aircraft systems to route sensor data to the computers, very possibly additional radios, a sophisticated data network with large capacity, large data warehouse computer systems and a system for the NTSB to examine the stored data.

The main reason the system seems unlikely any time soon is that there is insufficient perceived benefit to offset the high cost of development and implementation. Both government and industry feel they have better things on which to spend their time, money and effort.

The prime issue of any capability that examines aircraft crash data is to improve understanding of accidents in the hopes of preventing them in the future. The "low hanging fruit" that Mr. Ridgely [Ref: S02] spoke of consist of issues such as increasing the requirement for recorded cockpit voice data from 30 minutes to two hours. The NTSB feels this change to the present methodology of crash data collection would greatly enhance their analysis capabilities, but even this seemingly simple change takes a lot of energy. Aboard many aircraft it requires different recorders, which is an expense to the operator of the aircraft. It requires FAA regulatory action. It has implications on certification and re-certification of the recorders, and on dispatch.

Other reasons the system seems unlikely are limited communications data link capacity of the VHF and UHF frequency spectrum, limited availability of SATCOM channels, perceived excessive regulatory burden on operators and no expected significant gain in recovery rates of flight data after air crashes.

Thus, it appears that a large, expensive, complicated system such as RTFDTS is not generally viewed as necessary or feasible at this time.

2. Technical Conclusions

It is possible to design, construct and mandate the system given today's technology, although there are aspects of the system that require further research and development, most notably a smooth data link hand-off that preserves the secure channel connection between the aircraft and the FDW across different communications media (i.e. SATCOM changing to VHF, VHF changing to UHF, VHF changing to SATCOM, etc.)

No unusual methods are required to develop any of the computer systems. It should be a fairly straightforward matter of system development.

3. Information Assurance Conclusions

There are no information assurance issues that are beyond the scope of present security technology.

a) Confidentiality.

To ensure confidentiality and privacy, secure communication channels, such as Virtual Private Networks, are recommended. Data warehouse systems should employ restricted access mechanisms and/or data encryption, such as multi-level systems and asymmetric key encryption.

b) Integrity

Integrity of transmitted data can be assured through the use of hashes and encryption techniques.

c) Authenticity

Assurance of the authenticity of transmitted data can be accomplished using features of the secure communications channel in combination with hashes and unique aircraft identification tokens.

d) Availability

Assurance of the availability of transmitted data can be aided greatly by development of a reliable communications data network with multiple available pathways for information flow from the air to the ground. Availability of stored data can be assured through a combination of reliance upon the operating system of the data warehouse, uninterruptible power devices and redundant systems.

C. FUTURE WORK OPPORTUNITIES

Areas for future work and research and development are:

- A method of smooth data link hand-off that preserves the IPsec (or other secure) connection between the aircraft and the FDW across different communications media (i.e. SATCOM changing to VHF, VHF changing to UHF, VHF changing to SATCOM, etc.)
- Development of frequency sharing or time division broadcast to help relieve the problem of limited SATCOM channels and VHF and UHF frequency availability.
- Regulatory changes with respect to requirements and Minimum Equipment List (MEL) concerns.
- TSO specifications for system components.
- Software and hardware development of the Flight Data Collection Computer (FDCC), Transmission Control Computer (TCC), Flight Data Warehouse (FDW) computer system and Flight Data Examination System (FDES).

APPENDIX A — ACRONYMS

14 CFR...........Title 14, Code of Federal Regulations
ACARS..........Aircraft Communications Addressing And Reporting System
AGL...............Above Ground Level
AIM ....Aeronautical Information Manual
ALPA ....Airline Pilot's Association
AOA ....Angle Of Attack
ATC ....Air Traffic Control
C&A ....Certification and Accreditation
CAM..............Cockpit Area Microphone
CFR................Code of Federal Regulations
COTS.............Commercial Off-The-Shelf (equipment or software)
CVR ....Cockpit Voice Recorder
DFDR ....Digital Flight Data Recorder
DHCP............Dynamic Host Control Protocol
DOT...............Department of Transportation
FAA ....Federal Aviation Administration
FAR ....Federal Air Regulation; Federal Aviation Regulation
FDES..............Flight Data Examination Subsystem
FDR................Flight Data Recorder
FDW ....Flight Data Warehouse computer system
FL...................Flight Level
FO ....First Officer
HF ....High Frequency
HTTPS...........Hyper-text Transfer Protocol (Secure)
IA ....Information Assurance
IAS ....Indicated Airspeed
IP....................Internet Protocol
IPsec ....Internet Protocol (Secure)

LF....................Low Frequency

MAC..............Media Access Control

MC.................Magnetic Course

MEL...............Minimum Equipment List

MF..................Medium Frequency

MH ....Magnetic Heading

MSL ....Mean Sea Level

NAVAID.......Navigation(al) Aid

NIACAP ....National Information Assurance Certification and Accreditation Process

NM ....Nautical Mile

NSA ....National Security Agency

NSTISSI.........National Security Telecommunications and Information Systems Security Instruction

NSTISSC ....National Security Telecommunications and Information Systems Security Committee

NTSB ....National Transportation Safety Board

RAS................Remote Access System

SATCOM......Satellite Communications

SSL.................Secure Socket Layer

TAS................True Airspeed

TC ....True Course

TCP................Transmission Control Protocol

TCP/IP..........Transmission Control Protocol/Internet Protocol

TH..................True Heading

TSO................Technical Standard Order

UHF...............Ultra High Frequency

VHF ....Very High Frequency

VPN...............Virtual Private Network

APPENDIX B — TERMS & CONCEPTS

14 CFR — Title 14, Code of Federal Regulations, covers aviation. It is the regulatory authority for the Federal Aviation Administration (FAA).

14 CFR PART 91 — The portion of 14 CFR containing regulations pertaining to all aviation operations regardless of type, and specifically to general aviation.

14 CFR PART 121 — The portion of 14 CFR containing regulations pertaining to air taxi operations.

14 CFR PART 135 — The portion of 14 CFR containing regulations pertaining to air carrier operations.

ABOVE GROUND LEVEL (AGL) — The distance between the aircraft and the ground (or water) beneath it.

AERONAUTICAL INFORMATION MANUAL (AIM) — An FAA publication containing a wealth of information about basic flight information and ATC procedures.

AILERON — A flight control surface located on the trailing edge of each wing. The ailerons are used to bank the aircraft, which turns the aircraft to a different heading.

AIRFOIL — A surface having some curve to it with the property that when moved through air it produces lift. Examples include a wing, rudder, aileron, and propeller or fan blade.

AIR CARRIER — An operator of aircraft that provides scheduled service, which could be passengers or freight. Examples include Untied Airlines, British Airlines, FedEx, United Parcel Service, and SkyWest Airlines.

AIR TRAFFIC CONTROL (ATC) — The system and personnel that deliver air traffic control services. The Federal Aviation Administration (FAA) handles ATC services in the United States. ATC services include collision avoidance, traffic separation, efficient traffic flow management and emergency authority in national security situations.

AIRCRAFT COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM (ACARS) — A radio communication system that is used to transmit data to and from an aircraft in flight.

AIRLINE — See “Air Carrier”.

AIRLINE PILOT’S ASSOCIATION (ALPA) — A labor union of professional pilots that is concerned with promoting and protecting issues of interest to pilots.

AIRSPEED — A measurement of how fast the aircraft is moving with respect to the air mass in which it is flying.

See also "Indicated Airspeed", "True Airspeed".

ALTITUDE — A measurement of how high the aircraft is above a certain datum.

See also "Above Ground Level", "Mean Sea Level", "Pressure Altitude", "Flight Level".

ANALOG — With respect to an electrical signal, a signal that varies continuously by some measure of strength (weak to strong).

ANGLE OF ATTACK (AOA) — The angle between the chord line of the airfoil (wing) and the relative wind.

See also "Chord Line", "Airfoil", "Relative Wind".

AUTHENTICITY — With respect to information assurance, a property of information such that the receiver has assurance that the sender is who/what (s)he/it thinks it is.

AVAILABILITY — With respect to information assurance, a property of information that guarantees the information is accessible (available) when it is sought.

BANDWIDTH — With respect to data transmission signals, a property of the transmission expressing the maximum amount of data that can be transmitted using the signal.

CAPTAIN — A required crewmember of an aircraft designated as being in command of the flight. The captain may or may not actually be manipulating the controls of (flying) the aircraft. Other crewmembers [i.e. the First Officer] may be manipulating the controls at a certain point in time.

CERTIFICATION — With respect to individual pieces of equipment or entire systems, an official statement by the FAA that the equipment may be used for aviation purposes.

See also "TSO".

CHORD LINE — The straight line between the front of the leading edge and rear of the trailing edge of an airfoil.

COCKPIT AREA MICROPHONE (CAM) — A microphone installed in the cockpit of an aircraft that is used to detect general sounds within the cockpit. It is one of the sensors used to collect information that is fed to the cockpit voice recorder.

COCKPIT VOICE RECORDER (CVR) — A flight data recorder that records voice communications, including those from the captain, first officer, second officer, cockpit area microphone, chief flight attendant, and passenger cabin (not all may be available on all aircraft).

CODE OF FEDERAL REGULATIONS (CFR) — The collection of directives established by Congress that govern a variety of activities in the United States, including aviation.

CONFIDENTIALITY — With respect to information assurance, a property of information that guarantees only the parties that should be able to understand the information actually do understand the information.

COURSE — The direction of flight with respect to a fixed reference, such as true north (for true course [TC]) or magnetic north (for magnetic course [MC]).

CRASH DATA — Flight data from an aircraft that crashed.

DIGITAL — With respect to an electrical signal, one that consists entirely of pulses of energy that are interpreted as either "0" or "1", that when interpreted singly or in combination form a meaningful piece of information.

DIGITAL FLIGHT DATA RECORDER — A flight recorder that records flight data in a digital format.

See also "Flight Data Recorder".

DISPATCH — The part of flight operations that is concerned with ensuring each flight has been properly flight planned. Flight dispatch carries equal responsibility for the safety of the flight along with the captain on board the aircraft.

Also known as "Flight Dispatch".

DYNAMIC HOST CONTROL PROTOCOL (DHCP) — A method used to assign dynamic IP addresses to new devices connecting to a computer network.

ELEVATOR — A flight control surface that allows the pilot to control pitch, which is the "up and down" motion of the nose of the aircraft.

ENCRYPTION — With respect to data, the intentional scrambling of data intended to prevent those who should not be able to understand the data from understanding it. To be effective, encryption must be reversible.

FAR PART 91 — See "14 CFR Part 91".

FAR PART 121 — See "14 CFR Part 121".

FAR PART 135 — See "14 CFR Part 135".

FEDERAL AVIATION ADMINISTRATION (FAA) — An agency of the executive branch of the United States government that exercises oversight of aviation.

FIRST OFFICER (FO) — A required flight crewmember designated to be second-in-command of a flight. The FO provides assistance to, support for, and emergency replacement of the captain. The FO may or may not actually be manipulating the controls at a certain point in time.

See also "Captain".

FLAPS — Secondary flight control surfaces attached usually to the inboard trailing edges of the wings that the pilot can use to increase rate of descent without increasing airspeed, or to provide additional lift during certain phases of flight (usually, slow airspeed operations such as takeoff and landing).

FLIGHT DATA — The collection of parameters that describe the condition of the aircraft, either in real time or historically.

FLIGHT DATA EXAMINATION SUBSYSTEM (FDES) — The part of the proposed Real-Time Flight Transmission System, the subject of this thesis, that is used by crash investigators to receive data from the FDW for use in post-crash analysis.

FLIGHT DATA RECORDER (FDR) — A flight recorder that records flight data, including such items as landing gear position, position of flaps, trim position, position of slats, position of rudder, position of ailerons, and airspeed, altitude, heading and vertical speed.

FLIGHT DATA WAREHOUSE (FDW) COMPUTER SYSTEM — The part of the proposed Real-Time Flight Transmission System, the subject of this thesis, that receives flight data from the Internet and stores it. It includes archive and data examination capability.

FLIGHT DISPATCH — See "Dispatch".

FLIGHT LEVEL (FL) — Height above mean sea level with respect to pressure altitude (29.92" hg).

See also "Mean Sea Level", "Pressure Altitude".

FLIGHT OPERATIONS — See "Operational Control".

HEADING — The direction in which the longitudinal axis (a line drawn from nose to tail) of the aircraft is pointed with respect to some reference, such as true north (for true heading [TH]) or magnetic north (for magnetic heading [MH]).

HIGH FREQUENCY (HF) — High radio frequencies (HF) between 3 and 30 MHz used for air-to-ground voice communication in overseas operations [Source: F01 Pilot/Controller Glossary].

HYPER-TEXT TRANSFER PROTOCOL (HTTP) — The set of rules for transferring files (text, graphic images, sound, video, and other multimedia files) on the World Wide Web.

HTTP concepts include (as the Hypertext part of the name implies) the idea that files can contain references to other files whose selection will elicit additional transfer requests [Source: S05].

HYPER-TEXT TRANSFER PROTOCOL (SECURE) (HTTPS) — HTTPS adds public-key cryptography to HTTP. HTTPS provides a mechanism to securely encrypt Internet transmissions, and positive identification of the server to the user and/or the user to the server through the use of public key certificates.

INDICATED AIRSPEED (IAS) — Airspeed read directly from the airspeed indicator [cockpit instrument]. IAS is subject to various errors and deviations that cause it to be different from true airspeed (TAS). These include pressure altitude, temperature and air compressibility.

INFORMATION ASSURANCE (IA) — Information operations that protect and defend information and information systems by ensuring their availability, integrity, authentication, confidentiality and non-repudiation. This includes providing for restoration of information systems by incorporating protection, detection and reaction capabilities [Source: A02].

INTEGRITY — With respect to information assurance, a property of information that assures the information is sound, un-altered, and, if received after having been transmitted, what was actually sent.

INTERNET KEY EXCHANGE PROTOCOL (IKE) — A method of exchanging encryption keys using IPsec [Source: I01].

INTERNET PROTOCOL (IP) — A DOD standard protocol designed for use in interconnected systems of packet-switched computer communication networks [Source: A02].

INTERNET PROTOCOL ADDRESS (IP ADDRESS) — A device's or resource's numerical address as expressed in the format specified in the Internet Protocol.

Note 1: In the current addressing format, IP version 4 (IPv4), an IP address is a 32-bit sequence divided into four groups of decimal numbers separated by periods ("dots"), commonly referred to as "dotted decimals." The IP address of a device is made up of two parts: the number of the network to which it is connected, and a sequence representing the specific device within that network. An IP address may be used on private intranets, as well as The Internet.

Note 2: Due to inefficiencies that have arisen in address assignment, available IPv4 addresses are nearly exhausted. A newer version of IP addressing (IP version 6, consisting of a 128-bit numerical sequence) is currently being developed. *Synonyms* Internet Address, IP Number [Source: A02].

<u>IP ADDRESS</u> — See "Internet Protocol Address".

<u>LOW FREQUENCY</u> — From 300 kHz to 300 kHz.

<u>MAC ADDRESS</u> — See "Media Access Control Address".

<u>MEAN SEA LEVEL (MSL)</u> —

(1) The average level of the ocean used as the base, or "zero" datum, to determine altitude above the surface of the earth.

(2) Altitude above mean sea level.

<u>MEDIA ACCESS CONTROL ADDRESS (MAC ADDRESS)</u> — A unique, usually non-changeable numerical address assigned to network communications hardware. Layer 2 of the IP stack uses the MAC address to refer to that specific hardware device.

<u>MEDIUM FREQUENCY</u> — From 300 kHz to 3 MHz.

<u>MINIMUM EQUIPMENT LIST (MEL)</u> — Specifies dispatch restrictions and limitations based on inoperative equipment aboard the aircraft.

<u>MODE A TRANSPONDER</u> — A transponder capable of operating only in "Mode A".

Mode A communicates a discrete, 4-digit octal code to ATC radar that is used for unique identification of the aircraft by the radar and ATC systems.

See also "Transponder".

<u>MODE C TRANSPONDER</u> — A transponder capable of operating in both "Mode A" and "Mode C".

Mode C, sometimes called "Mode Charlie", adds altitude reporting capability to Mode A.

See also "Transponder", "Mode A Transponder".

<u>MODE S TRANSPONDER</u> — A transponder capable of operating in "Mode A", "Mode C" and "Mode S".

Mode S adds data communication capability to Mode C.

See also "Transponder", "Mode A Transponder", "Mode C Transponder".

<u>NATIONAL TRANSPORTATION SAFETY BOARD (NTSB)</u> — With respect to aviation, a federal agency that is concerned with the safety of flight. The

NTSB is the primary investigative body in charge of determining the cause of air crashes.

NAUTICAL MILE — The kind of miles used in aviation. One nautical mile (NM) is equal to 6,076 feet, or approximately 1.15 statue miles.

According to "How Stuff Works":

> "A nautical mile is based on the circumference of the planet Earth. If you were to cut the Earth in half at the equator, you could pick up one of the halves and look at the equator as a circle. You could divide that circle into 360 degrees. You could then divide a degree into 60 minutes. A minute of arc on the planet Earth is 1 nautical mile. This unit of measurement is used by all nations for air and sea travel" [Ref: H01].

NAVAID — One of several radio navigation systems that allow a pilot to navigate with respect to a fixed geographic point regardless of flight visibility. By using NAVAIDs, a pilot is able to navigate through clouds or on top of clouds when the ground or other visual references cannot be seen from the aircraft.

OPERATIONAL CONTROL — Control over the initiation, continuation, diversion or termination of a flight in order to ensure the safety of that flight operation [Source: T01].

Also known as "Flight Operations" and "Ops Control".

OPERATOR — With respect to aviation, the person or business that operates an aircraft. Examples are a private citizen who owns an aircraft, any of the air carriers, a charter company, an agricultural application business or a flight school.

OPS CONTROL — See "Operational Control".

PRESSURE ALTITUDE — Altitude with respect to standard atmospheric pressure, which is 29.92" hg or 1015.2 hPa.

REMOTE ACCESS SYSTEM (RAS) — In the context of this thesis, a method of accessing a computer system via means other than the Internet, such as through a dial-up telephone connection.

REGULATION —

(1) (n) A specific binding directive.

(2) (v) The act of applying binding directives. For example, the FAA is charged with regulation of aviation.

RELATIVE WIND — Wind direction of the airflow produced by an object moving through the air. For an airplane, the relative wind flows in a direction parallel with and opposite to the direction of flight.

RUDDER — A flight control surface that allows the pilot to control yaw, which is the lateral (side-to-side; left and right) motion of the aircraft. It is the movable surface on the "fin", or vertical stabilizer, at the rear of the aircraft.

SATELLITE COMMUNICATIONS (SATCOM) — A communication system that uses radio signals transmitted to and/or from a satellite in orbit above the earth.

SECURE SOCKET LAYER (SSL) — The Secure Sockets Layer (SSL) is a commonly used protocol for managing the security of a message transmission on the Internet. SSL uses the public-and-private key encryption system from RSA, which also includes the use of a digital certificate [Source: S05].

TECHNICAL STANDARD ORDER (TSO) — A minimum performance standard issued by the FAA for specified materials, parts, processes, and appliances used on civil aircraft [Source: F03].

TRANSMISSION CONTROL PROTOCOL (TCP) — A set of rules used along with the Internet Protocol (IP) to send data in the form of message units between computers over the Internet. While IP takes care of handling the actual delivery of the data, TCP takes care of keeping track of the individual units of data (called packets) that a message is divided into for efficient routing through the Internet [Source: S05].

TRANSPONDER — A device installed in an aircraft that responds to a query by a ground radar system by sending certain information to the radar, including a discrete 4-digit octal code, the aircraft's pressure altitude and possibly also some digital data.

See also "Mode A", "Mode C", "Mode S".

TRANSPONDER (MODE A) — See "Mode A Transponder".

TRANSPONDER (MODE C) — See "Mode C Transponder".

TRANSPONDER (MODE S) — See "Mode S Transponder".

TRIM — A secondary control surface that allows the pilot to equalize aerodynamic forces on a primary control surface. Trim is used to eliminate the need for flight control inputs for the primary service that would otherwise be required to hold the flight surface in a particular position. The most common trim device is the elevator trim, followed by aileron trim and rudder (most commonly found on multiengine aircraft).

TRUE AIRSPEED — The actual speed of the aircraft relative to the surrounding air mass.

ULTRA HIGH FREQUENCY (UHF) — The frequency band between 300 and 3,000 MHz. The bank of radio frequencies used for military air/ground voice communications. In some instances this may go as low as 225 MHz and still be referred to as UHF [Source: F01 Pilot/Controller Glossary].

VERY HIGH FREQUENCY (VHF) — The frequency band between 30 and 300 MHz. Portions of this band, 108 to 118 MHz, are used for certain NAVAID's; 118 to 136 MHz are used for civil air/ground voice communications. Other frequencies in this band are used for purposes not related to air traffic control [Source: F01 Pilot/Controller Glossary].

VIRTUAL PRIVATE NETWORK (VPN) — A secure communications channel for data networking incorporating IPsec.

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APPENDIX C — TRANSCRIPTION OF INTERVIEW WITH TIMOTHY RIDGELY, BOEING AIRCRAFT COMPANY

This conversation took place between Tim Ridgely and Paul Schoberg at Boeing Corporate Headquarters in Everett, Washington, on 4th June 2003, at 9:30 AM. Mr. Ridgely is a senior engineer working in the area of cockpit voice recorders.

KEY	
[R]	Tim Ridgely
-S-	Paul Schoberg

-S- OK

[R] That's bad, because they are one of our two major suppliers.

-S- Who is the other one, then?

[R] L3

-S- L3, yeah.

[R] You're going to see them, right?

-S- Yeah, I'm going to see them. The guy at L3 sent me a pretty neat little paper he wrote. Pretty short, not nearly as extensive as the one you sent.

[R] Frank Doran?

-S- Frank Doran, yeah.

[R] A guy we work with typically in engineering.

-S- He seems like a really sharp guy.

[R] Yeah, he is. (unintelligible)

-S- OK, I thought what I would do is first of all thank you for giving me some of your time.

[R] Sure.

-S- I'll just give you a little background of how I've came to this point and exactly what this is.

[R] Yes.

-S- As you know, I'm here from the Naval Postgraduate School, which is in Monterey, California. That is one of two military postgraduate institutions. The other one is the Air Force Institute of Technology, which is in Dayton, Ohio. Basically, the school is concerned with all sorts and manner of technical education in all the sciences -- everything from space to any kind of engineering you can think of, mechanical, electrical, computer science, physics, math, all that kind of good stuff.

A typical student there is O-3, O-4; we've got some ensigns, we've got some commanders. But, typical is O-3 or O-4. 1500 students roughly, maybe half of them are Navy officers, a third of them are Marine officers, the other sixth are other services -- Air Force, Coast Guard, Army -- and we have a lot of foreign military as well. There are 20 or 30 different countries represented. And then, there are about 20 civilians of which I am one.

I come to that school as a civilian under a program called Scholarship For Service, which is essentially where the government pays for a degree and then you work for the government for a period of time. And, I happen to be there earning a Master of Science in Computer Science with an emphasis on Information Assurance, which is a fancy way of saying computer security. Now, our director, Dr. Cynthia Irvine, she goes around the world, mostly in government, and finds people who want things done because one of our requirements is to do a thesis, a Master's thesis.

One of her contacts recently has been the FAA and they've given us several projects to do. One of them is this one. There's several others, too. Biometric authentication of pilots is one that's being completed now and there's some work being done in the way of clearance delivery, flight planning, that kind of stuff. All with an emphasis on security.

[R] You know, they've got a job opening there at the FAA in D.C. for recorder people. I don't know if you saw that. It's not really for computer security and that kind of thing, it's more the recorder's use of data, rule making, and so on, with the FAA in D.C.

-S- Well, how did I get in this one? Frankly, they had a problem trying to find somebody they felt like they wanted to put on this data recording because the typical student there doesn't know a whole lot about aviation that's in the computer track. I happen to be a certified pilot, instructor, blah blah blah, and have been in the business a long time, so they said, "Hey you, how would you like to work on this project?" And, I thought, yeah that sounds like a really nice project.

Now, I am in the beginning stages of what I'm doing. I think you saw the thesis proposal, so you're roughly familiar with the kinds of things I'm doing. I'm gathering information at this point. Really, what I'm after is (A) In general, can this type of thing be done?; (b) How can it be done?; and, (C) How do you secure it? Obviously, me thesis has to move toward (C).

So, the reason I wanted to come up here and talk to somebody at your company was to find out (A) What have you done in the direction of work recording flight data off the aircraft? What kind of thinking has gone into it, if anything. What has your direction been? Do you care? This is kind of a "let your hair down" thing here. Tell me the truth. If this is something that Boeing is not interested in, doesn't care, or will respond to when the FAA comes along and says, "Do this" that's fine. Things that go into that are: * Is it worthwhile? * Is there enough crash data that is not available where something like this makes sense? And, I realize that as we go into the future we are looking at lots of stuff. FDR data, CVR data, video, and the amount of all of that is increasing.

Now, this [referring to Boeing document 1] was highly interesting. When I got this, I said to myself, "OK, I'm going to change the names, I'm going to submit it as my thesis, and say There You Go." Because, essentially, there's a lot of stuff in here.

[R] A lot of people were involved in that. I wasn't myself, but one of my colleagues attended, represented Boeing in that forum, and there were a number of industry ... the industry was well represented. The RTC, NTSB, FAA and a number of suppliers and airlines were involved.

-S- I kind of see this as a statement of the problem. It's more, all right, these are some of the things that are involved, but it wasn't really a "here's how we're going to proceed". It was kind of a look-see at the problem.

[R] And that was only one of many, many, many, many, MANY issues.

-S- And, I will say this also. When my computer science faculty approached me with this, they said, "Oooo, really cool, really neat idea, nobody has ever thought of this before." So, they thought this was interesting, too, in terms of the depth of looking at it that has been done. So, I've gone through this whole thing and talked to Frank Doran, so I'm starting to spool up a little bit.

[R] OK. So, like I say, there wasn't a whole lot in here, but there were a few pages worth of their thoughts.

-S- Well, the working group 2 had the most interesting stuff to me.

[R] ... back in this "B". And there was a tiny bit up front in section 10, but back in "B" ...

-S- Is that way toward the back someplace?

[R] Yeah ... [shuffling through paper looking for the section] ... you may not have brought that stuff with you. There were a bunch of ...

-S- I may not. This is the only thing I got from you. It doesn't have any "D"'s.

[R] OK. Well, you're welcome to take this with you [referring to Boeing document #2]

-S- OK.

[R] But they did talk some classic data link technology, high speed data link for accident investigation, infrastructure costs, technical issues, so there are a few pages.

-S- OK. Top level. What's your feeling. How do we do this?

[R] We can talk pretty informally. I am... Let me give you my background.

-S- OK.

[R] ... and what I can offer you. I've worked at Boeing for 18 years. I have worked FDR systems in the past. Currently, I'm working CVR. I'm a project engineer.

-S- So, you know Jim Treacy down at FAA then.

[R] I know who he is. He's not my systems and equipment counterpart. I work with Paul Sider in the local FAA. He's my specialist. Or Tim Chong in the past. Jay Yee. In Washington, the focal is George Cassodie. He's working on the rule making for upcoming recorder requirements.

-S- This exact stuff, then.

[R] Well, we can talk about that briefly. I'm the DER. I don't know if you're familiar with FAA DER's. I'm a designated engineering representative (DER), so the FAA appoints me to find compliance of design with applicable FARs. So, I cover the voice recorder system.

-S- So, you're a dual ... you're a Boeing employee, but you're appointed by the FAA for their work.

[R] Right.

-S- You work on (unintelligible)

[R] It's, ah ... I think it worked well and it's been in place for many, many, many, many, MANY years. There's always room for improvement. So, that's kind of my perspective. As far as my non-DER role, I'm a lead engineer. We do production releases to build the airplanes, whether it's wiring or schematics or functional test requirements and parts lists and those kind of things. We work with the suppliers for new development of parts. We support in-service airplanes. We support the factory in the build process. We support airlines in service that have (unintelligible) in field service offices about our systems, and we coordinate with industry and suppliers and regulators around the world in development of parts and certification of parts - getting them on airplanes. That's kind of my role. I have a limited amount of time. I've done basically no preparation for this. It's the direction of management. We're all under tight budgets and nobody is paying us to do this.

-S- I understand that.

[R] We're happy to tell you what we know and work with you and we want to support you in your efforts and the FAA in their efforts in working with you ...

-S- I appreciate it.

[R] ... in what I can do. Some of the information I can share because ... well, some of it I can't share because I don't know it.

-S- OK.

[R] If you ask me details about the SATCOM data rates, I don't know.

-S- That's OK. That's not really the focus of this conversation.

[R] So, there may be technical things I just don't know the answer to, and other things are either proprietary data that need to stay within the company. So, with that said ...

-S- Frank Doran is real good about technical information. He and I will go over all that kind of stuff.

[R] Yeah, and I haven't seen that paper. I'll ask Frank to send me a copy of that.

-S- Actually, you're welcome to take this copy.

[R] OK.

-S- He wrote it. It's not real detailed, it's just kind of top level.

[R] Is this a recent thing? I don't see a date on here.

-S- It's within two years.

[R] They participated in this forum, I believe, and many other industry forums.

-S- He didn't mention this to me, but kind of veiled maybe did mention it. Well, you know, he talked about something like this, but he didn't mention RTC.

[R] Well, I know there were a number of people and I think this list ... who was on a different approach and stuff. I know Honeywell attended this. So, how can I help you? What specifics?

-S- Ultimately, I'm going to get down to the security of such a system. And, when we talk security, we use a CIA model. It's nothing to do with Central Intelligence Agency, it's C-I-A, which is Confidentiality, Integrity of the data, Availability of the data, and the other "A" we don't care about. Anything that feeds into those areas is what ultimately I'm concerned with. So, I'm imagining that when we have a system in place and we're beaming data all over the world, we're using SATCOM, we're using VHF, we're using UHF, we're using XHF -- whatever isn't defined at this point. And, to secure the data so that it gets someplace is really what I'm going to be after. Now, what that means depends on what those pipes are. So, I guess the first question I have is: How do we do this? Is it your feeling that a satellite system is ultimately where something like this would end up, do you think a hybrid system? I've even thought in terms of ... you know, no airplane virtually flies in its own airspace. You've got other airplanes around. So, maybe we beam data to other airplanes. The chances they all would crash at once are probably pretty low. Somehow we collect the data. I don't know. Have you guys thought at all about that type of issue, and what's your feeling about how to implement beaming this kind of data off of the airplane.

[R] I guess part of it goes back to the bigger picture of why would we do this? Would we need to do this? Maybe you don't want to discuss that, maybe that's a given.

-S- No, I do want to discuss that. Because, frankly, let me tell you the end result here. From what I've seen, talking to Frank, looking at this document, all this kind of stuff, my bottom line feeling right now is probably cost-benefit isn't there. But, a lot of what I'm trying to do is maybe find that it is there.

[R] We can talk a little about the need and then go on. Make an assumption that yes there is a need and we'll go from there.

-S- OK.

[R] You know there's always challenges with recovering the data. There's been a continual evolution of the recorders, from wire recorders to foil recorders to mag tape and now to solid state. Duration has increased from 30 minutes to two hours on the CVR side, and 25 hours on the FDR side.

-S- I didn't know that.

[R] As far as CVR, the FAA current rule is only 30 minutes, but there's a recommendation out of the NTSB for two-hour recording. It's pretty clear that rule making is coming.

-S- OK.

[R] Two hour duration.

-S- Is that going to retro everybody?

[R] The anticipation is that there will be a retrofit requirement to go to two-hour recorders, which will make them all solid state.

-S- It probably will help a lot of people, because I imagine they're smaller, lighter weight.

[R] They're smaller, lighter, and you don't have the maintenance. That's what the airlines care about. Then you don't have to mess around with capstan and motors and grease and their liability is much, much higher. And it definitely is lighter. So, we expect to have to go to two hours and the FDR has been 25 hours. As far as I've heard, I haven't heard anything from industry about concerns of increasing the FDR duration. That's a pretty long duration. You get a number of flights, typically, in there. That's been sufficient. There has been talk about making the CVR even longer than the two hours, but most of the investigators that I've talked to feel that two hours is sufficient.

-S- What about video? Do you see any requirements for that coming down?

[R] There is a recommendation from the NTSB, I don't know if you're aware of the NTSB website. You may want to look at some of those recommendations the NTSB puts out.

There is a recommendation for flight deck video or image recording. The current thought process is that they should be at least the same duration as the CVR, because they want the correlation between the video and the audio and the FDR as well. Whether that will happen or not, I don't know. I participated over, actually over about the past five years in Euro-K, if you've ever heard of them. The RTCA? They're the European equivalent. European organization for civil aviation electronics, and they had sub-committees that worked on MOPS (minimum performance specs) for all the recorders, and just recently released a document called ED-112, which replaced other industry documents that called out from FAA TSO's. I don't know if you're familiar with the TSO. The current ones, C-123A for example, is the voice recorder, it refers to ED-56A. This new document replaces that and combines the requirements for all the recorders. FDR, CVR, image, data link, con-v recorders, deployables. It's all in one document. So, there's a section in there for flight deck image recording. There were a number of accident investigators that made the case for it. There were representatives from the pilot unions, ALPA and IALPA, and there were some restrictions on the data and they were supportive of it, whether they could sell it to their constituency. And those guys always point to, well, you've got stuff in place ... you know, in the U.S. it's a law: protection of the data, but in other places it's not. You know, the Cali accident was ...

-S- ... a good example ...

[R] It was right on TV.

-S- The voices are out there.

[R] Yeah, so the union guys often point to well, you can't control the CVR repeatedly, how do you expect us to believe you can control the image, and it's much more sensationalism and we don't want somebody to see their loved one flying into the ground. It's much more graphic.

-S- You see, now, that if you start talking about feeding all this data over some sort of data link, securing that is an issue.

[R] Right. It's a very big concern. So, the image recording... You know, the NTSB is pushing for it. Whether the FAA buys into it, I don't know. I think there's a lot of behind-the-scenes wrangling. There's been a lot of rule making that is expensive for the airlines. They went to 88 parameters for the FDR recently, ah, they're talking about adding more parameters aimed toward the 37 [Boeing 737] rudder stuff. There are expected rule making changes and we can talk more detail about going to a two-hour recorder, data link recording, battery backup for the recorders, and so on. And so there's a push kind of either get it in there now or it's going to be a long time because we can't just keep piling up new major requirements on the airlines.

-S- Especially these days.

[R] Right. So, the NPRM -- I don't know if you know the rule-making process -- but, that hasn't come out yet. So, I think there's a lot of discussion behind the scenes, whether that would be included in there and then industry comment or the GAO or the other dollar counters and budget people would say that would be prohibitive for what you gain out of it.

-S- See, that's the bottom line that I've heard is that we can have very sophisticated recording on board the aircraft, but we don't lose the data that often, so does it really make sense to put in all this infrastructure to beam it off the airplane? Let's go to a perfect world. All right, we've got 5,000 airplanes flying out there. Every one of them has got video, cockpit voice, FDR, all this stuff's happening for 48 hours in all cases. It's all being beamed someplace. It's in a secure box on the ground and everybody is happy. But, that's prohibitively expensive.

[R] There are a lot of costs associated with that. Working with our air safety organization investigators, I have not had a put from them saying, "Hey, this is good. We need this. We want this."

-S- Yeah, if you talk to the NTSB there general position is, you know what ... in most cases we don't even need the flight data. We can figure it out from other means. You know, if we have it, oh isn't that nice. That's some of the older guys that will say that to you.

[R] Well, they sure like to have everything.

-S- Of course they do.

[R] ... you know, and your brother's birthday, the wind speed on the day your mom got married, and so on.

-S- OK, so ...

[R] As far as your answer to when you do this, I mean, you know, there always is difficulties ... and, well, often times there's difficulties in recovering the data. One whether ... there has been a lot of stuff where the airlines just haven't maintained the system, or haven't confirmed that all the parameters are working, so there's move in the industry to require periodic checks of all the parameters.

-S- I thought there was a yearly...

[R] Yeah, but there are certain things that aren't detected without fail modes, that aren't detected realistically unless you're in specific flight modes. So, there's a lot of discussion about how thorough that check needs to be and what can you dispatch ... you know, can you get MEL relief without having all your mandatory parameters in place and operating.

-S- Right.

[R] So, there's a lot of ... you know, that's one issue about having valid data. Going to the longer duration helps, going from tape to solid-state helps. There is concern about recovery of the data, ah, locating the data using the beacons -- the underwater locator beacons -- there has been some discussion about the robustness of those and the attachment of those to the recorders. If you find a beacon and it's way over there ... and the recorder is way over there ...

-S- ... way over there ...

[R] ... buried in the mud somewhere, and so there's work of ... this new document increases the testing that's required for crash survivability for having the beacon attached to the recorder under the various G-tests that the manufacturers have to do as part of their TSO qualification. So, those are some of the issues.

There is also some discussion about deployables. Because some people say, you know, the thing is in the water and it's 3000 feet or 5000 feet of water and we've got to hire the Navy with their deep sea submersibles and that's expensive and it takes a month and we can't find the thing, and so there are ... the manufacturers of the deployables are saying, yeah - everybody should have this.

-S- I've got to say that makes a lot of sense to me. Somehow you determine that it's time to deploy and you shoot the thing off, and moments later the crash occurs, and we've got all the data. Maybe that's the simple system. Maybe that's the best infrastructure and not all this communications stuff, I don't know.

[R] Did I see in your papers or your resume that you're an Air Force guy?

-S- Yeah.

[R] One of the guys that participated in this industry forum was from the Air Force Safety Center in Albuquerque. I think they're in Albuquerque.

-S- I want to say they're at Kirkland.

[R] And, so, this guy was responsible for the recorder readouts and representing the Air Force interests. The military is going to more COTS type stuff because they want to reduce their costs whether it's AWACS planes or Air Force One or wedge-tail stuff for the Australian Air Force. They're going more toward the TSO commercial recorders, so this guy participated. So, he may have some insights for you. I can give you his name and his number as far as deployables or down links and data, as far as how they do that.

-S- Oh yea, I'd love that.

[R] I'll remember to do that. So, he may have some insight from the military.

-S- Efford Smith...

[R] Effort Smith, yeah.

-S- You think in Albuquerque.

[R] Yeah, I have his business card at my desk.

-S- OK, great.

[R] And I'll give you Allied names and numbers. Allied has been in it a long time. The two we use are L3, which used to be Lockheed and Loral, and they all go back to Fairchild or Sunstrand Allied, or Honeywell to Allied Signal to Sunstrand. So, these guy shave been it in a real long time and they have participated in many industry forums, whether it's ARINC or RTCA or this Euro-K. They participated in this. At least, L3 is involved in the maritime recorders and the commercial ships and so... yeah, it would be good to talk to some of the Allied people.

-S- I think this is a prelim, that's why it isn't quite as extensive.

[R] Yeah, this was a (unintelligible) I got e-mailed from Jim Cash who is an NTSB guy. This is off the RTCA. I don't know if you guys at your school or something belong to RTCA. If you're a member then you can go onto their website and download stuff for free, otherwise you've got to order and pay.

-S- I'm sure that's not a problem. We are the Navy [laughter].

[R] You may already be a member and you've just got to get the password and then you can go in and get the soft copies and (unintelligible).

-S- If I can jog us aside for just a second ...

[R] ... sure ...

-S- ... the FAA wanted us to do this. It appears to me almost like the left hand doesn't know what the right hand is doing, because the people we were talking to were kind of ... oooo, gee, new stuff here. Then there's RTCA and they're doing all this. I don't know...

[R] Well, they were right in the middle.

-S- Yeah, that's right. This time comes from the FAA chief and the NTSB chief writing the letter saying, do this. So, I almost question well, why am I doing what I am doing then, but...

[R] Well, it's kind of unfortunate. We all live in the real world and the dollar budgets, but there was this recorder symposium-seminar in D.C. this week. Actually, right now as we speak. Unfortunately, nobody here could attend. But, I think it was an SAE-sponsored forum with the NTSB, and not just aviation but maritime and trains and trucks and all kind of recorders. That would have been interesting. And there will probably be some minutes and materials coming out of that, so you might want to watch the SAE website or NTSB. The FAA as far as our contact, or my contact, (unintelligible) it's more with ... you know, I talk to one or two people there and that's it, and they're focused on the recorder side and I don't know what all various down linking, free airspace, and all that stuff that's going on.

-S- We've got another problem, too. Suppose we send Qantas over the Pacific toward Sydney and somewhere left of Fiji something goes wrong. How do we get the data out there? That's a different problem than if you're over Cleveland.

[R] They still send stuff all the time, right?

-S- That's right.

[R] They've got to send position reports whether it's by voice or by data ...

-S- Yeah, but those are different animals. That's a lot less data and a lot less out. If you're talking flight parameters you're talking a bunch of slices per second and it either has to happen real-time or it has to happen in a burst of some kind, or whatever. So, I'm still trying to figure out what's your feeling? Can a satellite component of this exist? Is that too expensive? Is there equipment on board the airplanes now that's basically there that could be used? I even had one guy come up to me and say, "What about all these cell phones you've got in your seat? Can't they climb on to that somehow?"

[R] Well, I mean there is ... and here we get into the proprietary stuff ... but, there is the "Connections by Boeing". It's been in some of the news lately with the (l.h.) with Lufthansa for Internet, for e-mail services.

-S- And there's some data there, yeah.

[R] There's significant data there. As far as the actual rates...

-S- ... yeah, if every passenger ...

[R] ... I couldn't tell you if I did whether it supports that stuff. I didn't know. This is just an L3 maintenance manual for the recorders, and so I was glancing at this (unintelligible). Yeah, they talk about digitize the stuff and then the rate of data stream going, you know, so here's the rates in the CVR ...

-S- ... per channel ...

[R] ... what they're stuffing into the memory. If you want to keep up with it then you've pretty much got to stuff that to the ground somewhere.

-S- And then you've got to figure you're not getting 100% of that in your transmission necessarily, so you've got to plan for more.

[R] Yeah, I don't know the overhead associated with the message transmission and the XBR rates, but I mean, you know, this gives you an idea of some of the rates, whether existing SATCOM systems or connections support that, I don't know.

-S- And video blows you out of the water. This is small compared to video.

[R] And video, you know, there's a lot of discussion of frame rates and resolutions. Is four times a second sufficient, is it not, for certain things is it ... you know, they're talking a general flight deck view. (unintelligible) You know, for the general environment in the flight deck versus looking at a display or something, or watching the crew actions.

-S- Crew actions and displays are two different issues. Crew actions are one thing, but you almost want to have a camera just focused on the instruments to see what they're seeing.

[R] Well, now, depends on what you're trying to accomplish. The resolution frame rates are driven by the need and what are you going to do with the data. If you're already recording the data on the flight deck ... or, on the flight recorder ... do you need to have a camera with high frame rate looking at airspeed on the display?

-S- No

[R] OK, so supposedly ...

-S- But, what about weather radar? We're not recording that. So, what is the crew seeing?

[R] I'm not an accident investigator. And how often, you know, if you see the jerky hand motion -- is that fine? -- or do you need to see a smooth motion? You know, you need to be ... the resolution ... do you need to be able to read stuff on the display, or just see that it's not blank, or see that it's not upside-down, or it's not flashing, or all garbled, scrambled data. What do you need? Are you looking for smoke, you know? Are you looking for the two guy struggling with some of the accidents, ah, theories that are going on. The guys are doing stuff and this guy's going like this, you know the non-verbal communication. So, there's a lot of discussion among these investigators of what really is the fundamental need, and then you get down to requirements that support meeting those fundamental needs.

-S- Again, in a perfect world you've got 60 frames per second and everything is perfectly clear and you're recording and downlinking all of that.

[R] Again, in this ED-112 document there are requirements for frame rates and resolutions and color or not color and all that stuff. You're right, with the image there's going to be more data. Another thing we expect rule making on is recording some data link messages. You know, all the clearances and all that stuff used to be by voice and it's all on the voice recorder. Well, now you've gone to data link messages and they're hitting buttons on a display and sending messages, so the NTSB is ... ah, some of this stuff's in ICAO and, well, we don't have rule making yet, but we expect it and the details are not clear what's going to be required, but stuff that's up-linked over VHF or SATCOM and displayed to the crew will need to be recorded somewhere.

-S- Is ACARS, are those transmissions, ACMS, that kind of stuff, is that recorded on the ground, do you know?

[R] We had some talks in these industry meetings. We had one meeting at SETA in Geneva. SETA is one of the two main ground stations that are used, as far as I know, for that kind of data -- ARINC and SETA -- and they said they were really adamant, we keep that data and we keep it for business purposes and quality control and for financial reasons, so much per bit and quality and keep the data and we can show our customers we're meeting our contracts and this is how much they charge. And they were adamant there is no regulation or law or requirement for us to keep the data for a certain period of time.

-S- Or, at all. As far as I know, I think they're right.

[R] So, as far as counting on ... and that's one of the reasons that a lot of the discussions were, "Why do we have to record this stuff on the airplane when all that stuff's on the ground?" Well, it's not always on the ground, and if it's on the ground it's not always easy to get to. So, the data link is an additional chunk of data that may be recorded on the airplane and have to be taken into account. That's not expected to be real soon (unintelligible) the data, though, but the (unintelligible).

-S- Well, RTCA basically said that anything leaving the airplane or arriving at the airplane needs to be recorded -- that affects the safety of flight (unintelligible). So, ...

[R] Well, I guess you have to have discussion with your accident investigator colleagues.

-S- Right.

[R] You know, obviously, well you know ... do I really care that they're saying "give me three cases of of whisky, two wheel chairs, and I want to stay at the Red Lion." Kind of "company-type" messages, and then ...

-S- Yes, I do.

[R] ... because that's a crew workload issue. This guy's talking about the hotel and he drives into the swamp in Florida. So, there are different issues, and the other guy says I ... I can tell what's going on, there's voice recording, and if there's crewmembers that survived I have those people. I have all the air traffic control radar data, blah blah blah blah blah. So, there is a lot of details about what needs to be recorded. RTCA ... you know, this report is a compilation of consensus of "the industry". It was intended to be a look out ten to fifteen years from now. What are the issues and what are the needs, kind of thing. Some of those come into rule making, I believe, and many of them will never become rule making. ARINC, Euro-K, RTCA -- none of those have any "authority" on an airline or an airframer or a pilot or an operator or anybody.

-S- (something about the FAA)

[R] Unless this stuff becomes, ah, a national agency requires it.

-S- To their credit, I think that the regulators don't want to put a whole lot on people if they don't have to.

[R] Right.

-S- In general. Sometimes they go a little overboard, but in general.

[R] And there's always that ... they always butt heads, you know, it's kind of like it takes four kids getting hit on the road and getting killed before a stop light goes in. It's a similar thing. The NTSB and the FAA butt heads often.

-S- Well, it's the classic FAA paradox. You know, on the one hand they're there to promote safety and on the other hand they're there to support industry.

[R] Promote the business.

-S- That's right, so...

[R] There is that concept, ah, that contention there. Getting back to "do we need to do this?" Like I say, I haven't had a big input from many airlines, from our air safety groups, saying yes we need to do that. Our counterparts in the NTSB have not pushed for that at all. I'm not sure whether it's because they ... not because they don't feel there's a need for it ... but, it's ... we'll make incremental improvements here rather than big-picture, huge steps. If we get two hours recorders and we get data link recording and we can get a ten-minute battery back-up for the recorders for when the ship loses power, and we make the beacon more robustly attached to the recorder, and we add some new parameters or increase frame rates on some surfaces, these are all great things and we would be real happy with that and we'll fight the other battle down the road.

-S- Right.

[R] I don't know.

-S- Well, hopefully, if we do good design on it and look at all angles and secure the thing and figure out exactly what it takes to beam stuff all over the place, we can make it painless to put such a system in. You've gone through this, obviously.

[R] Parts of it.

-S- Did anything jump out at you as a whole? Something that was not considered overlooked.

[R] No, I think it was pretty thorough, they had a number of meetings and ...

-S- That was my feeling, too.

[R] Pretty good collection who have many, many years and different perspectives. But, I'm not sure about the airline participation, but I know that there were a number of vendors and air framers and NTSB and FAA. Many of the people I've met from other industry meetings and they're they experts. They're the national resource specialists for recorders and for other issues there. I'm sure the downlinking, one of the things would be the privacy concerns. In some places that's a real issue and some places it's not. We have an industry meeting in Kiev and we had some of the regulators from the Ukraine -- "What is the problem?" We tell the pilots that this is the way it is, they salute and say yes, and that's the end. What do you mean, privacy, unions, pilots? We tell them what to do. Here, ALPA and IALPA are strong and they have probably some legitimate concerns. I'm sure that would be one of the concerns. Is the data accessible? The encryption, the protection of the data is always, you know ...

-S- If you can encrypt it, somebody can decrypt it.

[R] Exactly. You hear about ... oh, you know, somebody found this little portal to get in and Microsoft has a patch out now, but we had 83,000 VISA bill accounts were accessed and pilfered and all it takes is one especially when somebody in the media, scrupulous ... unscrupulous, I'll give you five million bucks if you give me that video of that British Airways flying into the ground.

-S- But, to be honest, the transmission of the data is probably not the weak link in the security there. It's the storage. We can use public key cryptography or any kind of cryptography or any kind of encryption that you want to imagine. Make it such that you'd have to have 50,000 super computers taking a billion years to crack the key, but then we're all gone and we don't care -- let 'em crack it. That's not the problem. The problem is somewhere along the line it's decrypted, it's sitting somewhere on a disk, whatever ...

[R] But, you do that today.

-S- There's your problem.

[R] You do that today. The ground air traffic control voice are all recorded and stored.

-S- Yes.

[R] They're stored.

-S- Right.

[R] Somewhere.

-S- They are.

[R] They are at the FAA or somewhere at the air traffic control centers, that data is sitting there for at least 30 days.

-S- I don't know if you've ever been to a center or anywhere else.

[R] I've been to the Auburn one down here.

-S- They have banks and banks of recorders. It's pretty old technology.

[R] Yeah, but they have that data.

-S- But, they have them.

[R] They're sitting there.

-S- A bunch of tapes.

[R] Yeah. And whether the newer ones have solid state, whatever, but in some media, some form, that data is the same data that you're talking about, is there.

-S- Now, if I'm United Airlines and I fly my airplane from Seattle to San Francisco and I land and I've got some data on board the airplane in the recorders, is it not true that I own that data as United Airlines? That's my data?

[R] I can't say this unqualified, but I believe the answer is yes. Now, they have certain obligations to keep that data in certain incidents or accidents for a certain period of time in the FARs, I think in the 121, the operator rules, they have to keep that data. But, I believe you're right. It's their data.

-S- All right. So, United owns the data. We've got pilot's unions, we've got all these people concerned with the privacy of the data, if we're beaming this stuff over some satellite link or some VHF link or something, who is recording it? Do I now burden the airlines to record it? Does Boeing offer the service? Does the FAA do it? Does the NTSB do it? And, if the FAA does it, now all of the sudden United's data is in possession of the FAA.

[R] Right, yeah, those are all issues ...

-S- That's the hole I've seen with all of this stuff. Everybody talks about well, here's what's on board the airplane, here's the recorders, here's the bit rates, here's what the SATCOM can do, here's all of this stuff and nobody really goes into OK now we're going to record it somewhere. Who is it?

[R] Right.

-S- And all that kind of stuff, so...

[R] And for how long who's going to control it and who has the right to it and the legal ramifications and the litigation and all that stuff.

-S- But, you see, that's a perfect avenue for somebody like me to come in because that is a computer science issue. It's an information assurance issue.

[R] Well, it goes...

-S- It goes beyond that, too.

[R] It goes far beyond that.

-S- It does.

[R] Who is going to record it? You don't have to be a computer science expert to do that, and what about litigation aspects?

-S- Exactly.

[R] So. I'm afraid I don't know. I don't have answers. Those are all good questions. But, as far as some of that data being there somewhere ...

-S- It is ...

[R] But, currently all of that data is sitting there somewhere.

-S- And then we have the non-investigatory aspects, too. A lot of the data is being used for monitoring maintenance status of all kinds of systems.

[R] And the FOQA program.

-S- Yeah. And can we use down linked data, would it enhance that at all? I don't know. Probably not because in that case, everything is on board the aircraft, the aircraft lands safely, you've got all this stuff recorded ...

[R] ... you've got a crew to talk to

-S- ... got a crew to talk to. Everything's happy, so.

[R] You know, we do down link stuff over ACARS now. Maintenance messages...

-S- Yeah, sure.

[R] Ah, (system) faults (time), that kind of stuff ... I'm an hour out ...

-S- ... yeah ...

[R] ... hey, here's the faults

-S- ... right ...

[R] ... come up with your plan, get the parts, because we've got to get turned around and let's go. Now, that data is down loaded, or down linked, through ARINC or SETA to the company to the airline.

-S- Yeah, I have a friend who is a dispatcher for QANTAS. She and I have talked about quite extensively from their prospective. She was quite amazed because I said, well, go out and find out what QANTAS is doing with this stuff. She came back and said, "Wow! These maintenance guys can talk to the airplane when it's in flight!" She was just amazed by that. And, you're right. All that stuff does fly around, but ... and, it's talked about in here, but in terms of data linking I don't know it's really that important. All right, there is a person who directed me to ask this question. I kind of asked it before ...

[R] OK (laughing)

-S- And it's probably a proprietary answer and you'll probably say I can't answer that.

[R] Ask it anyway.

-S- All right. It's kind of back to the "what systems are on board the airplane that we can tie into?" You've got Internet links, you've got cell phones, you've got that kind of stuff. Is it your feeling ... you see, the issue here is that we don't want to put more equipment on the aircraft if we don't have to. Can we tap into those existing things, do you think?

[R] Not everybody ... there's no guarantee somebody is going to have a cell phone.

-S- But, if Boeing sells a 757 to somebody, what's on that airplane?

[R] It varies widely by customer. The only communications system that you can be guaranteed to have is VHF. Not everybody has HF, many do, but if you're flying domestic routes or if you're flying in Japan, if you're within VHF range, why pay another $100,000 or whatever (I'm pulling that out of the air) to equip your airplane and carry that weight around. Non-revenue ...

-S- ... please note that Mr. Ridgely has just quoted a price for ...

[R] it's a binding contract [kidding]. So, the only ones you would be guaranteed of is VHF, and not everybody gets ACARS. Everybody gets two VHFs for voice and there's a third VHF dedicated to ACARS if they get it. Many people have HF. Not everybody has SATCOM, many people do. No commercial planes we deliver have UHF.

-S- Right, that's for the military.

[R] So, you've got VHF always. Sometimes you have HF. Sometimes you have SATCOM. Like I talked about, the new "Connections", and I don't know the details of the frequency range that it operates or the data rates.

-S- OK, so for the record, there isn't an array of systems that you can pretty much count on that we can count on.

[R] No.

-S- That's what I told him, but it's nice to hear that.

[R] You have the VHF, the VDL Mode 2 VHF data link, VHF data radio, and I don't know the details of the data rates there, but I believe that was an improvement over data rates and quality and we can use that VHF data link. And that's probably your best chance of having something on the plane that you're not going to have to add. It may only be on certain routes. When you get into some of the other routes, you know transoceanic routes there's different requirements for equipment. If you're operating in a FANS environment, you might have to have stuff coming on (ADSB) for automatic position reports. But, if you want to get something on every airplane, whether it's flying from Chicago to Detroit or Chicago to Hong Kong, you can't count on the same equipage on those planes at all.

-S- OK, so then the follow-up question I guess would be alright so the two VHF systems are guaranteed, but come on, I mean these people are spending millions of dollars for an airplane, what's another $100,000. Most people do get a bunch of stuff.

[R] We deliver many, many, many airplanes with no HF.

-S- I don't think I can use that for data link anyway.

[R] Well, there is HF data.

-S- Yeah, but...

[R] We are delivering that. ARINC has a bunch of ground stations worldwide. I think the data rate would not support something real-time. SATCOM is quite expensive. The larger airframes typically have SATCOM, flying the long, transoceanic routes where you may be flying polar routes and stuff where you some more problems with HF and you need good communication. I don't know whether the data rates would support that. And then you get into the other issue. Hey, what about my dispatch? I've got all of this automatic down link, so I don't need my on-board recorders any more, right?

-S- I don't think that's ever going to be the feeling.

[R] So, can I dispatch without the download or do I have to have that working to dispatch? Can I get MEL relief? So, those are all peripheral questions.

-S- Yes, those are good questions.

[R] You know you can dispatch now with one recorder or the other not working for up to three days, but you've got to have the other ... you can go with no CVRs as long as you have the FDR or vice-versa.

-S- Right.

[R] Fails. Or faulty and you can't repair it for 72 hours. So, that would be part of (unintelligible).

-S- Well, at this point, the language that the FAA has been using with us on this project is "Backup Recorder", which would indicate to me that it's not an MEL issue and gee, it's nice to have, but yet it's funny. It's kind of like taxes, you know, it never goes away and it always gets worse.

[R] Yeah. So, as far as equipage, there's nothing that's going to be on every airplane today that would support what you need.

-S- So, we would be talking about an additional system. Now we're talking to the airlines, we're saying you pay this money.

[R] Right. Or, it could be an optional system today that would need changes. Maybe the SATCOM doesn't support the data rates and it would need to be updated, improved, more robust in order to do that. So, either a new system, requiring a system currently that exist that is not mandatory on every airplane, making that mandatory. Or, taking a system that is mandatory, improving it to meet the needs, or developing a new system basically that's dedicated toward that stuff. All those have ka-ching, ka-ching written all over them.

-S- Yes, they do. Alright, and then just, another ... one other thing that I'm thinking here. This is kind of a technical question. We've got data flowing around on an airplane on some kind of data bus. How accessible is that? Is it easy to, I'll use word "steal" the data?

[R] Well, the existing ... ah, I can talk about some of it, I don't know all the details. The CVR, for example, right now our audio systems on the airplanes are basically analog audio systems.

-S- They are analog.

[R] Yeah, I mean a lot of the control between the various audio components is digital control, but the audio signals, basically, we have analog audio going to the butt end of the airplane to the CVR. It's digitized and stored, which is in the recorder.

-S- OK, so the recorder has an analog input and it ...

[R] Yeah, four channels, four analog inputs. Left seat, right seat, observer, and the area mic. You've got four separate audio lines going back there, now newer airplanes which we are in the middle of building, may or may not have a completely digital audio system. The FDR currently has a digital bus. You have an acquisition unit, whether it's a (unintelligible) video or a flight data acquisition unit or it's a in the main cabinet or it's modular electronics. That is a digital bus going back to the recorders. So, I mean, that data is there on that bus. You know, what the fan out is of that or the loads, but I'm sure it could handle another load. Some of that stuff is parallel to the FDR and the QAR - quick access recorder or maintenance recorder, whatever you want to call it - out of that same bus, whatever you want to call it.

-S- And this is a ... is there, ah ...

[R] It's a serial bus, it's not very fast. I don't know the details or whether they're (? "ARINC 717") or the bus characteristics (unintelligible) hook into the ARINC.

-S- Are you putting things like ethernet on board the airplanes now?

[R] There is no ethernet in the recorder systems. As far as I know, there may be ... there's ARINC 629 stuff on the 777, the new airplane may or may not have ethernet. As far as I know, we're not putting ethernet on the existing models, but that's certainly being considered and I think the A380 is going to have ethernet.

-S- How many years in the future is it going to be before we do this?

[R] Do what?

-S- Downlink stuff. 30?

[R] You sound confident that it will happen.

-S- I think it will, you know, 200 years from now. I don't know. 100 years, 50, 30...

[R] I don't know. Maybe, maybe not. Then you get into the into the ground side of it, just the logistics of, you know, who's going to own the stations? Where are the stations going to be? You've got a downlink station in Africa, well that station's not working because everybody vandalized it and stole the gas and the generator. Nobody likes to fly in Africa because all your ground navaids are not working because they've been pilfered.

-S- Yeah, but who needs ground navaids when you've got satellites?

[R] They come down somewhere. And whether they all come down in one place or they come down various places and are linked over landlines and are linked to the repository of the data ... I don't know. I came across this. I make no claims about this. We're moving, so I'm going through data. So, I came across this sometime, I think somebody did their little pitches at one of our industry meetings ...

-S- ... sure ...

[R] ... and this is purely a sales pitch, but this talks about ... you know, this is some company with their products of down linking data and they've looked at some of this. Monitoring medical and patient monitoring, environmental, internet access, data security, reliability ... here's some scenarios on why you should give you all your money so we can do this for you. Ground stations that they're proposing and here's our card. I will not be keeping this. I will be tossing it; you're welcome to take it and do with it what you will.

-S- OK, I'll probably be tossing it myself.

[R] It's another source of information. That's a couple years old and they're in Toronto or somewhere.

-S- Yeah.

[R] I have not felt the push from industry to do this.

-S- Which makes me again wonder why the FAA has sent us a pile of money to, among other things, send me here to talk to you when (unintelligible) this sort of thing. They seem quite interested in this system. Anyway, I ... is there anything else you can think of to add from a Boeing perspective?

[R] No, you know we are fully committed to safe airplanes and accident investigation and having the data that you need to resolve what happened and prevent that from happening again. It's something that is very important to us. We support that actively and we support industry activities. Like you say, at the Euro-K I went, and another guy went to the future flight data collection committee, an ARINC committee that is working on new specifications. We just haven't had a push at all from the NTSB or the FAA or the JAA or airlines to do this. I don't know if Frank told you something different, but ...

-S- No, actually Frank pretty much said the same thing. He basically said they have looked at it and it's a problem that's too big to chew right now. Yeah, we're aware of it, but.

[R] I think that's part of it, like I said the investigators know they only have so many chips and they want to use them where they can kind of get the most for their literal dollar and their political dollar, and they would much rather have two hours recorders and require a 10-minute backup for the voice recorder, so you have recording if you lose ship's power, and data link recording and possibly video recording on the flight data than push for something like this.

-S- Because the incidence of data loss is just not that big.

[R] Usually we almost always recover the recorder. Almost always. I'm sure there are cases where it wasn't, or one recorder was and the other one wasn't, but ...

-S- Didn't they have that in Pennsylvania. Didn't they get the, ah ...

[R] I mean, there are cases. I don't think they got 'em, in New York City I don't think they got the recorders.

-S- I don't think they got anything there.

[R] Yeah, they just melted. They were just lost in the rubble, so. But, I think the incidences of those are very, very few. The NTSB guys can give you ... I assume you're going back to D.C. to talk to them. Dennis Grosse is the guy I work with, and he's the national (? reco) specialist for recorders, so I'm sure he can quote this accident or that accident. But, my impression is that there were very, very few where the recorders were not recovered.

-S- Actually, the bigger incidence is unreliable or missing data or spotty data, that kind of stuff.

[R] Or the recorder was damaged and we couldn't retrieve the data, and that's been ... the incidences of that have been reduced by ...

-S- ... better equipment ...

[R] ... having solid-state recorders, more robust you know. 3400-G impact and 1100-degree C fire, it's a pretty robust recorder. There is a recommendation from the NTSB to have dual recorders, one forward and one aft, to increase having the data available. So, there are cases where one recorder couldn't get off because the tape was melted, well solid state addresses that. Well, it happened 40 minutes ago and they only had a 30-minute recorder, the two-hour recorder addresses that. Some changes in the beacon attachment helps locating it in a timely fashion, a cheaper fashion, much better. Having the (? con-B) recorders, which may or may not become rule making would increase the changes of having that, in recovering at least one of those recorders.

-S- I'll have to speak like a flight instructor. Better pilot training ... just don't crash.

[R] There you go. But, you know, they're very useful in the incidents and not the accidents. We support that stuff and if there is a big push to actually do that we participate actively in that because that would have a big impact on us (unintelligible) our customers.

-S- Well, that's the bottom line for you folks. I mean, you want to have the best product, and...

[R] Yeah, right.

-S- Yeah.

[R] We want a safe product. We want a good product. We want a product people will buy it, over and over.

-S- Yeah, exactly.

[R] So, you know, we're for safe airplanes. Once again, I'm speaking from a knothole. I'm an engineer. I've participated in industry with a number of investigators and manufacturers and worked with our air safety people, but I'm not an accident investigator and I don't speak for the whole Boeing company, but from my position I don't see any push to do this and I would question its value.

-S- Yeah.

[R] There are probably are other things that the money could be spent on that would have a bigger impact on airplane safety than downloading data, whether it is crew training, or whatever it is.

-S- I suspect my final report back to the FAA is going to go along the lines of, well, for these reasons boom, boom, boom, boom, boom, boom, boom, it doesn't look like this is the direction we want to go. Exactly what you're saying. Let's get some of these other things first. That's been my impression since I first got into the project, but you know you have to slice it and dice it. They want that answer, so...

[R] Sure. Ask the same questions over. Ask different people. Ask different questions and think about it, and the people at Allied may have a different opinion and when you go back to the NTSB they may have a ... they may be working behind the scenes to do this ... a recommendation.

-S- And I was ... I told you on the phone the other day that I had run across something at NASA that's along these lines, and I had hoped to bring something here to you that you could see. But, unfortunately, the guy that I'm working with has been on vacation the last couple of weeks, so I haven't got the stuff myself to give to you.

[R] That would be interesting.

-S- But, if I do get something that you may be interested in I could send it up to you.

[R] That would be good. I'd like that.

-S- But, basically what I know is that they have a system like this that's in a Lear 25 and a 757 and they're flying it around the skies and I've seen shots of the video that's been downlinked.

[R] Oh yeah, I mean we down link stuff all the time in the flight test program, whether it's audio or video.

-S- Right, but their ... NASA's thing was exactly this. So, ah, they were trying to put together a system that, in some fashion, I'm not sure what communications link they're using or any of that kind of stuff, but I do know they're flying it around the sky right now. So, if I run into any more juicy stuff on that ...

[R] Yeah. That would be interesting.

-S- They're somewhere in Ohio. Dayton, I think. It's not Wright-Pat, it's somewhere out that way, though. Well, I would like to once again thank you for your time.

[R] Sure.

-S- Thank you to your management for allowing you to be here and ...

[R] You bet. Hopefully, you got some information that will be worthwhile to you.

-S- Well, among other things you have confirmed a lot of things that I already thought, but you've give me some additional things to think about, so that's good.

[R] And, you know, when you talk to the ALPA and the IALPA guys, you may have or plan to, but, they may have ... I can give you names and numbers for the guys that participated in the recorder ... recent industry activity, and they kind of represent those unions in the recorder world, so they may have some ... there may already be a ...

-S- ... position paper out ...

[R] ... by the union guys.

-S- You'll notice there is a line through this [referring to Paul Schoberg, Thesis Proposal] and another date.

[R] Yeah.

-S- The reason for that is that when I first wrote the thesis proposal for this project, it included ALPA, it included a lot of stuff, and my computer science-focused director said, "What are you talking to ALPA for? Where's the computer security for that?"

[R] Are you really evaluating whether this should be done, or are you just saying assuming we've got to do it, here's how it could be done, but in order to do that you would need to know all the concerns. What are the top-level system requirements that my design has to address, and privacy is one of them, so that's why I would talk to ALPA.

-S- I will be talking to them, it's just that I had to scale it down and what I sent you is the scaled down version, but it's going to go back up again.

[R] There's a guy at Northwest who is a captain there who is ALPA that has participated in some of these meetings. He is interested in flight deck video recording privacy issues, so he might be a good guy. Lindsay Fenwick.

-S- At Northwest in Minneapolis?

[R] Yeah. I'll have to see if I can get his name there's a guy from BA as well, Malcolm Carey. Lindsay Fenwick. Everett Smith from the Air Force. ALPA, and then you'll need Honeywell names here in Redmond.

-S- Wonderful.

[R] Any other contacts or organizations that I might be able to give you to link into?

-S- No, I think that's more than enough.

[R] More than enough.

-S- I'm going to be down at the FAA this afternoon in Renton.

[R] On this issue?

-S- Yeah. On this issue.

[R] Is Paul Fider part of your audience?

-S- He isn't. Jim Treacy and Tom Kraft.

[R] They're not the regular working guys that I would ...

-S- No, I was doing a little snooping. You're anonymous, by the way. I went out on the Internet and said "who is this guy?" and the Internet said "I don't know."

[R] Good.

-S- But, the fellow I'm going to meet this afternoon has got stuff out there. He's been in the business 35-some-odd years and he's worked on, you know, blah blah, all this kind of stuff.

[R] Yeah, yeah that will be good.

-S- He's going to be an interesting man to talk to.

[R] I know who they are and I've talked to them on the phone, but they don't know who I am.

-S- Who?

[R] Never heard of him. That's the response you will get from them.

-S- Sometime that's good.

[R] But, yeah, my ... (? if they hadn't been qualified) they actually changed, they wrote papers (unintelligible). Jay Yee, Paul Fider, Kim Chong were the three guys that (unintelligible).

-S- Alright, sir.

[R] Alright. Well, let's, ah ...

-S- Thank you, thank your management ...

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APPENDIX D — TRANSCRIPTION OF INTERVIEW WITH JAMES TREACY, FEDERAL AVIATION ADMINISTRATION

This conversation took place between James Treacy and Paul Schoberg at the FAA office in Renton, Washington, on 4th June 2003, at 2:00 PM. Mr. Treacy is a senior executive with over 35 years of service with the FAA and in the aviation industry. In his career he has specialized in avionics and cockpit configurations, including work with flight recorder systems.

KEY	
[T]	James Treacy
-S-	Paul Schoberg

[T] He's associated with Boeing Connections, and he used to be an EMC guy, I guess he still is, but anyway they have a research program or had a research program with the FAA in which they did some work into this area of transmission of voice and flight recorder stuff.

-S- Connections did?

[T] Yeah. Well, it's either ongoing or just nearly finished. They haven't published the report as I understood it, but if we got permissions from the administrators of the research that might be available for you.

-S- Good.

[T] But, of course, they're talking about transmission over the Connections network is probably what they're doing. I actually don't know much about what they did, only that they explored that idea of transmitting the information in real time.

-S- Well, let me tell you where I'm at, at this point. This is for me a relatively new project that I'm just getting into and making contacts and finding out about a bunch of things.

[T] OK.

-S- It was interesting talking to ... do you know the man's name? ... Tim Ridgely? You may not know him. He said you wouldn't know him, so...

[T] Mmmmm ... don't recognize the name, no.

-S- And he said that when you said that I should say, "Good."

(laughter)

-S- Anyway, he is a ... he's in the CVR area dealing with whatever he deals with in that direction ...

[T] OK.

-S- ... an engineer type. And, he was a real good source of information. One of the things he sent to me a little while ago was this gem right here. It's an RTCA report.

[T] OK.

-S- You don't really need to look through it.

[T] Is this the standard for the recorder that they published?

-S- No, this is sort of a blue sky "what can we do?" working group. I think it's near the beginning here ... *(shuffling through papers)* ... anyway, it doesn't matter. Basically, what this is, this is a group that is formed in response to a letter written by Garvey and Hall, jointly.

[T] OK.

-S- They said: "Form a group, go forth and figure out what we're going to do with flight data recording, the future of flight data recording. Where are we going to be at in the year 2015?"

[T] OK.

-S- And this report details a lot of stuff, they broke them into three working groups. One of them had to do with technical issues, one of them had to do with regulatory issues, and one of them had to do with privacy issues.

[T] OK.

-S- Alright, and so they broke it down very well. They identified a lot of problems. They said, "here's what we can do today, here's what we think we can do..." but nobody actually solved the problem. They just kind of basically set it out and said, "This is it."

[T] Right.

-S- This is one source of information that I have found very enlightening. Another one, I'm talking with L3 Communications down in Sarasota, Florida.

[T] OK.

-S- I'm sure you know them.

[T] I know the company, but I don't know their connection with the recorder systems.

-S- They're a manufacturer.

[T] OK.

-S- Tim over at Boeing was saying oh yes, we work with them, and I mentioned the guy I'm talking to and he says, "Oh, I know Frank. You bet."

[T] Yeah.

-S- They had some interesting things to say, too. They evidently looked at the problem and they have kind of sliced it and diced it and talked to people in satellite communications, people in all kinds of communications, they've looked it from the standpoint of what their recorders do, so they've looked at it also.

---< Interruption >---

[T] Sorry.

-S- No worries. I did not record that, by the way.

[T] It's OK.

-S- OK. Ah, so L3 has looked at it and they've talked about it and he's been engaged in things. So, what I'm finding is there's an awful lot of people out there that are working on it. Another group I've been in contact with is NASA.

[T] OK.

-S- They're actually flying the system. They've got it in a Lear 25 and a Boeing 757 and they're flying around Ohio and they've got things bouncing around, and ...

[T] Oh, I didn't know that, either.

-S- So, that's pretty interesting. I don't have detailed information on that because the gentleman is on vacation at the moment, he'll be back next week, so...

[T] OK.

-S- So, there's a lot of industry, government, lots of people are looking at the problem.

[T] Right.

-S- Frankly, when I got this thing, I said, "Ah, well I'll just change some of the names and hand it in and say *there's my thesis*." It's pretty complete, it really is.

[T] *(laughter)* Yeah.

-S- So, I'm looking at all of this thinking, "Why am I here?"

[T] OK.

-S- Now, to get to that ... I don't know if you know the background of what exactly it is I'm doing and where I'm from and all that kind of stuff.

[T] I really don't know that much about ... other than it looked as though you're primarily interested in the way in which you would actually deal with the data that would come down and how you would sort it and save it and all that stuff.

-S- Yeah. Well, briefly, I'm at the Naval Postgraduate School. It's one of two military postgraduate schools ...

[T] I'm somewhat familiar with it, yeah.

-S- And I happen to be one of probably less than 50 civilian students down there. Basically, I'm getting a master's degree in computer science with a computer security emphasis.

[T] OK.

-S- And, the person who kind of runs that show down there, Dr. Cynthia Irvine, she's one who is kind of a go-getter. She goes out and finds people to do research of her because every one of us has to do a thesis of some kind.

[T] Right.

-S- And she ran into some FAA sorts back in Washington and said, "You know, some of the guys back in Monterey are talking about the idea of beaming this stuff off the airplane." And everybody in Washington said, "Oooo, neat! Let's have you look into that." So, they came up with some money, that's why I'm here, ah ...

[T] OK.

-S- ... and voiced some interest and so on. So, I wrote a thesis proposal. I think you have a copy of it.

[T] Ah, no, I don't think I got it.

(talking over each other about the thesis proposal)

-S- I have a thesis proposal and basically what I did is I looked at what the problem statement was and said, "Alright, I'm going to do a FL500 look at this thing" ...

[T] OK.

-S- ... and kind of answer the question of <u>can we do this?</u> <u>Is it cost effective?</u> <u>How do we do it?</u> And so on.

[T] Right.

-S- Now, given that I'm in the security end of things I have to eventually get to some security topic within this.

[T] Right.

-S- But, to get there, you've got to know how you're going to do it.

[T] Yeah.

-S- Right.

[T] Right.

-S- So, I've looked on the Internet and you are prominent!

[T] *(laughter)*

-S- Evidently you have had a very noteworthy career ...

[T] Varied career, I think you would say.

-S- ... very noteworthy time in the FAA. So, I feel like you're a very good resource for all of this. Let me give you the bottom line of what I have seen so far.

[T] OK.

-S- Neat idea. Wow. Probably ain't gonna happen.

[T] Ah, that's probably right, yeah.

-S- So, my ... what I probably have to do is probably get to the root of why it's not going to happen.

[T] OK.

-S- Now, Tim this morning, from Boeing's perspective, had some very interesting things to say. I'm kind of interested now in the FAA's take on such a thing, being in the position of regulation of the thing.

[T] OK.

-S- And, also a little bit of how are we going to do this if we do it? Suppose, in a perfect world, we had video at 60 frames per second and we had 10,000 data parameters for flight data ...

[T] OK.

-S- ... and we had 50 channels of audio and all of that was getting beamed to the ground someplace and we're storing it, and every airplane out there including a Cessna 172 has this stuff.

[T] Yeah.

-S- Alright, so...

[T] Right ... OK.

(laughter)

-S- How do we do that?

[T] Right. Yeah. Right. Well, there's a ... yeah ... even if you had it all, how are you going to sort it all out? That's a huge problem.

-S- Yeah.

[T] Yeah, OK, you probably ... well, I don't know how much you know about the FAA. Despite what they may say on the web we are a very reactive organization and it's a very mature industry. We've been beating on these problems for 40 years, probably, and a lot of the solutions are about as good as they can get in some of the things and there's some things that you can't fix. There's a lot of conservatism. Don't change it if it's not broke, kind of thing.

-S- Sure.

[T] And, ah, the recorder business is kind of an oddball. After all, nobody wants to have a crash and it doesn't do anything to prevent a crash other than the next one afterwards if you find what went wrong. So, we all recognize we need to record it, but it's kind of a lower priority as far as the quality of the systems because in and of itself it can't cause the accident, or we make pretty sure that it can't because of the way it's connected it's not going to kill your communications and it's not going to mess up your control systems even though it's recording parameters from it, so the main safety stuff for that is it's ... you buffer it or you have it from secondary sources so that even if it shorts out you're not going to lose the primary stuff that the crew needs to fly the airplane.

-S- Mmmm hmmmm...

[T] So, from that perspective it's kind of an after thought almost. Yet, the accident investigation is very costly, very expensive, extremely difficult. Something I'm very happy that I don't get involved in personally except once in a while.

-S- Let me stop you right there if I might.

[T] OK.

-S- I know you're not NTSB, but I'm just curious. What do you think the NTSB would think of this kind of system?

[T] Well, I've talked to them when we talked earlier. They're not great fans of it.

-S- Mmmm hmmmm...

[T] It depends, OK? They're primary concern is that the data that's recorded is complete. The idea of transmitting it from an airplane that's in distress bothers them, because ...

-S- It bothers me, too.

[T] ... because you're not necessarily going to be in an orientation or a capability to transmit the signal to a receiver that can get it.

-S- Mmmm hmmmm...

[T] ... especially if you're out of control and you're not pointed any particular direction.

-S- Right.

[T] So their concern is primarily if this were in addition to the recorders they're all for it, if it's a replacement for the recorders, uh-huh [negative] they don't like it.

-S- Well, the description from the FAA of my project is backup FDR/CVR recording.

[T] And the big problem with that is expense. I mean, if it's a backup, what's the payoff? You've got to equip all the transports if you're going to do it ... with it ... in doing that, really the equipage is only to translate the information from the data concentrators to some sort of a data link and send it.

-S- Mmmm hmmmm...

[T] But, any ... right now any installation that's not absolutely necessary is just not happening because of the economics of the airline industry.

-S- Sure.

[T] Right now they're flat on their back and under water. So, ...

-S- So, the last thing they want is Jim Treacy to come down and say, "Hi, I'm from the FAA, we're here to help you, and the way we're going to do that is..."

[T] Right. Or anybody ... right ... we have this idea and it's not going to increase their efficiencies, it's not going to increase passengers, it just has no economics except negative for them.

-S- Maybe, maybe not. I mean, there is a lot of talk in reports like this about recording parameters for the purpose of evaluating equipment, you know, ah, maintenance trends, that kind of thing. You don't need to beam that across the airwaves someplace.

[T] You don't have to send that, that's right.

-S- So, the recorder ...

[T] And, they already do that. There are programs like GAIN and the quick access recorders and things like that, that are not done as part of the FAA necessarily, ...

-S- Right.

[T] ... but they're done as part of the airline's operations to do just as you suggest, to improve their turn around time for things that have failed on the airplane, to let them know what's gone wrong so they can fix it easier, troubleshooting, and also the FOQA stuff, which stands for Flight Operations Quality Assurance ...

-S- .. quality assurance ...

[T] ... I think, yeah. Which is kind of tracking to see how the airplanes are going, to see if there's something wrong with the operating procedures, to see if there's something wrong with the way the crew interacts with the airplane, in some cases for the ... some of the airlines like American, for instance, has a program where they are looking for mistakes that the crewmembers make to see ... a pretty good program, from what I understand of it ... to see if either there is some quirk that kind of leads people astray. It's trying ... kind of a no-fault kind of thing. You know, the FAA ...

-S- It would have to be because ALPA is going to go nuts if ...

[T] Right. It's kind of fledgling thing with the FAA's cooperation with them, and I think a couple of other airlines may have similar things, but the FAA has a traffic cop mentality. We're going to write you a ticket and you're going to pay the fine. We'll pull your ticket, you know, and you can't fly. So, we're not friendly with guys who make mistakes. And yet, a lot of the time ... so, as a result, you don't get the information about the fact that the mistake was made in the first place, so you can't fix it.

-S- Yeah.

[T] So, if it's a no-fault kind of thing, at least you can find out what's going on and, you know, unless the guy is absolutely egregious ... that's one of the basis of these programs ... unless, you know, it's willful violation – they're drunk, or something – it's a human mistake. Let's try to find out why it happened and see what we can do to fix it in the future, that kind of deal. But, that's not prevalent in the industry, it's much more the punitive kind of things, even though they're trying to change it, but there's a lot of suspicion about things like that, so... Sometimes you get cooperation, sometimes you don't. We're kind of off the subject.

All those things are there, most of that stuff is not transmitted in real time.

-S- Right.

[T] You've got the bandwidth problems, you've got the network problems, too, because right now about the only thing you have is the ARINC network and the company radio data links, which are pretty crude data links, but they're actually out there, and they use them for airplane AOC (airplane operational communications), sort of, it's flight plans, weather, passenger requests, stuff like that.

-S- Meanwhile, we have Internet connections now where theoretically every passenger on the plane can plug in the computer and ...

[T] Well, it's ... they're starting ... that's right. And yeah, and that's a possibility. All of that, of course, is ... we generally look at that as saying that's non-essential and you don't transmit anything that's really important or necessary over it, but you can use it, that's true.

-S- Mmmm hmmmm...

[T] I don't know that there are a whole lot of airplanes other than a few that have that capability, but they're sort of coming. They're in there for first class and a few places.

-S- One of the questions I had for Tim this morning was what is there on the airplane that we can piggy back on and have it become this kind of system?

[T] Right.

-S- And he smiled and he said that if you buy an airplane from us, you get two VHF radios. You got any questions?

(laughter)

[T] Yeah, you've got ACARS data link. Right.

-S- Three if you've got ACARS.

[T] Right. Yeah. But, you know, the airphones are fairly prevalent on a lot of the airplanes, at least in the business class and the first class cabins, and the system is there.

-S- Well, alright. We're successful on the war on terrorism. Every terrorist is dead. The economy is going great guns. The Dow is through 20,000. People are flying left, right and center. There's not enough capacity out there. Airlines are turning people away and they're charging everybody $10,000 and they're just very rich. OK.

[T] Yeah.

-S- This is going to happen in seven years. So, now we have all of the money in the world to play with, it's approaching the year 2015, which these people are talking about. How do we do this?

[T] Yeah. Right. I thought about that a little bit. I haven't really sat down and looked at it the way you probably would when you look at it. I think, just given the physics of the bandwidth that you're dealing with and the amount of data that we're talking about, it would seem like you would need something that if you were going to do it, it would be a selection, or there would be a ... you wouldn't transmit all the time, but you would send it out when you're in trouble. That probably does not help you for some kinds of accidents, although it depends on how you trigger the transmission.

-S- You're flying a 767 into the World Trade Center. As far as the airplane is concerned, it's fat, dumb and happy.

[T] No, it's not, actually. You get various kinds of warnings, and that's what you could kind of think about, or at least that's one possibility. As you approach the ground like that, you would get ground proximity warning system alerts.

-S- True.

[T] If you're about to collide with another airplane, you would get TCAS alerts.

-S- But, the Trade Center doesn't have TCAS.

[T] Well, it doesn't have TCAS. No, that's a different scenario: you hit another airplane.

-S- Yeah.

[T] But, if you're flying in cruise configuration that close to the ground, you get a GPS [sic] warning. It will give you one.

-S- So, what you're saying, then...

[T] So there are things on the airplane which can alert the system to say *start transmitting, there may be a problem* ...

-S- Yeah.

[T] ... rather than transmit all the time, which is costly expensive. But, that's probably a refinement rather than, you know, how would you actually do it.

-S- I think it's very important, because if you've got 5000 airplanes and they're all transmitting, "I'm out here in cruise, I'm out here over Cleveland" ...

[T] Yeah, and ...

-S- ... as opposed to the four that are doing something strange. Ahhh ... it's a big difference.

[T] Right.

-S- Now, I don't need all this huge network, and...

[T] Right. Well, it's ... the reception part of it is still there.

-S- OK.

[T] That's there the satellite ... and the expense, too, because if you were to transmit to the ... I've always been kind of a fan of low altitude satellites because of the low power and the pretty simple kinds of transmitters that you need in order to connect to them, but the problem for that is ... for the full-time system ... is the expense of each call.

-S- Mmmm hmmmm...

[T] But, if you're not doing it all the time then, well, it really isn't all that much of a factor. So, you know, it's those sorts of things that you can look at.

-S- So, you would say, then, that there's ample ways of the airplane determining by itself *I've got to transmit now*.

[T] In addition to the crew just having emergency ...

-S- ... having a button ...

[T] ... he hits 7600 on the ... transponder code.

-S- That was actually part of NASA's thing on their system that they're flying around. It's a two-part system. One is the data going someplace and the other is a panic button.

[T] Yeah.

-S- That's what they call it.

[T] Yeah, right.

-S- Mmmm hmmmm...

[T] I agree. That makes sense. Not always, you know not all the accidents happen that way, so ... they don't know they're in trouble in a number of cases in the ... and the, ah, but ... those are refinements, as I say, it's not the basic problem. But, some sort of filter on the amount of transmission is most likely necessary because ... of course, very fortunately for us we don't have an accident all that often.

-S- Right.

[T] And so, it doesn't make sense to transmit 360 days a year and full-time when ...

-S- Yeah, we'll let the on-board systems handle, you know, the day-to-day recording and stuff.

[T] Right. I don't know. The other kind of questions, would we mandate something like this? Probably not. The video people are kind of interested in the video.

-S- Mmmm hmmmm...

[T] The ... it's mainly from trying to sort out what happened because from recorded parameters you can infer a lot. The accident investigators at NTSB are really pretty sharp.

-S- Mmmm hmmmm...

[T] But, we've had a few accidents here in recent years where you're not recording the parameters, you can't tell exactly what happened, ah you're ...

-S- Or somebody goes like this [making hand gesture] in the cockpit and you don't know.

[T] Yeah. Right. Yeah. And we're still at somewhere between 60-70% crew error is probably cause, so having more information about what's going on in the cockpit probably makes good sense if you're going to improve things in that area. And there, you've got all of those kind of security and privacy things. If the ALPA guys today, as you probably know, the voice recorder is erasable. So, they come in and can erase what they said. They're not going to be happy about TV cameras. You know, you've got all of those political, labor kind of problems that go with it.

-S- That's right, and then you also have this issue: it's one thing if you have a recorder in the back end of the airplane, or one in the back and one in the front, is the ...

[T] Yeah.

-S- ... proposal now and everything is on board the aircraft, but as soon as you start beaming it through satellites and now people are out there, it's in the wild ...

[T] Right.

-S- ... ALPA's going to go nuts with that, I think.

[T] Yeah. Right.

-S- Mmmm hmmm...

[T] Right.

-S- ... unless it's absolutely secured somehow.

[T] Right.

-S- And even then...

[T] Right.

-S- And you can probably answer this one. If I'm United Airlines and I fly from point A to point B and I land the airplane, I've got an airplane with recorders and they're full of data.

[T] Right.

-S- I own that data.

[T] Right. That's right.

-S- Now, I am under certain obligations to release it, you know, if there's certain conditions met.

[T] Right.

-S- OK. So, if we had this kind of system and we've got, say, a satellite network out there and we're beaming the data across, who is going to record it?

[T] Ah...

-S- Is the FAA going to have a nice, big computer someplace?

[T] Probably not. No.

-S- OK, so now we're mandating the airlines ...

[T] ... to put this on and now somebody has got to use it. Is it going to be the airlines? They're not going to want it. And, ah, the NTSB would like it.

-S- Sure.

[T] And the FAA would probably like it if they could use it for tracking ...

-S- Ah huh ...

[T] ... but they're going to hate to pay for it.

-S- Yeah.

[T] So, who pays for it is a really interesting question.

-S- Yes.

[T] Yes. I can't give you an answer to that one. The FAA tends to think that it's, well, the operators and the manufacturers have the primary responsibility and we kind of look over their shoulders. So, we hardly ever do anything if we can say that the manufacturers ... it's the manufacturer's problem to actually solve it.

-S- Yeah.

[T] And, ah, the work together kind of thing is ... it's difficult because of the competing interests, but there is interest in doing that. In order to make something like this work, though, you would almost have to have it for something other than just the accidents and that makes it really tough to ... how do you release it for that? How do you make it ... I'm a big fan of the no-fault idea.

-S- Mmmm hmmmm...

[T] I don't think there are many aviation professions who are willfully violating the rules just to see if they can get away with it ...

-S- Nah...

[T] ... they're generally mistakes. And, people make mistakes and, you know, we're trying to make sure they don't get killed as a result of them.

-S- At least not Part 121, you don't find that kind of flying.

[T] Yeah. Right. Right. And even the small guys, they're not as well qualified, I know that I'm a pilot myself and not a good one ...

(laughter)

[T] So, in fact I'm not ...

-S- Well, sir, I'm an instructor and I can help you with that!

(laughter)

[T] But, you know, it's complex business and it's easy to make mistakes.

-S- Yes, it is.

[T] Anyway, off the subject again. Yeah, I don't have an answer for you on who would pay. That's a tricky one, but I think to have it ... to get it going ... you would probably need to be something more than just for accident investigation, otherwise there is no benefit to be had that would justify the expense.

-S- Right, and when you start thinking about the unique thing here being transmitting it real-time, what's the benefit of that other than accident investigation?

[T] Right.

-S- So, the NTSB ought to pay for it.

[T] Yeah.

-S- They ought to have the computers on the ground.

[T] Yeah, except that they're going to say, "Oh, but we don't trust it, you know, so we want the stuff and ... we want the stuff from the tapes, too." But, certainly, that would be the problem if it were the full-time one. If it's only transmitted from the airplanes that are in distress, well that's probably a different story.

-S- Yeah.

[T] It's not that huge a job, so... Especially if you're only talking about the 121 carriers, maybe the 135 carriers, if you start going into the business jets and things like that then it gets more difficult, I think.

-S- Yeah.

[T] So, I don't know, so ...

-S- Well, a lot of those guys ... they're not required to ...

[T] ... they don't have to have ...

-S- ... collect flight data anyway, so ...

[T] A lot of them have it, but they're not required to.

-S- Right. It's been described to me that if you look at the wish list, suppose you call the baseline 12 parameters on the FDR and 4 channels of audio.

[T] Right.

-S- And some kind of analog recording. Alright. There's your baseline. And the wish list is moving that forward so it's more reliable, better data, so forth.

[T] Right.

-S- That something like this is way out on the end, that ...

[T] ... I think that's right ...

-S- ... you'd like to get two-hour recording mandated first, which sounds like it's going to happen. Solid-state equipment.

[T] Yup.

-S- Digital audio, stuff like that.

[T] Improved audio would be a big help.

-S- Yeah.

[T] Ah, yeah. Actually, it's ... there's a simple solution, but you can't get it implemented and that's have the headsets required, because the audio quality in the cockpit because of the background noise with the area mic is very difficult ...

-S- Yeah.

[T] ... especially on some of the older airplanes. Even on some of the new ones it's pretty bad. They've paid better attention to the audio quality in the cockpits, and so they're a little easier. But, mostly ... I don't know if you've ever listened to some of the real recordings, but the tapes are nearly unintelligible.

-S- Yeah.

[T] So ...

-S- Actually, I haven't, I've never ... well, that's not true. I've heard a couple of them.

[T] Yeah. Yeah. It depends. It depends on where the microphones are. The ones that come over the interphone is really pretty good.

-S- Mmmm hmmmm, sure.

[T] But, naturally you would expect it to be.

-S- Yeah.

[T] But, the area microphone where the ambient noise sources are closer than the crewmembers to the microphone, they're pretty tough.

-S- Yeah, but isn't the purpose of that the ambient noises?

[T] Hmmm?

-S- Isn't the purpose of that microphone ...

[T] No, not necessarily, because the crewmembers don't use ... necessarily use the interphone for their communications, they don't wear the headsets necessarily.

-S- Oh, I see what you're saying. That's what you meant by headsets required, OK.

[T] Yeah, unless you're speaking into your microphone, and you don't have to, you have the hand out.

-S- Well, thinking of my own flying, you're right. I prefer to take the cans off the head and talk to the guy.

[T] Mmmm hmmmm...

-S- Mmmm hmmmm...

[T] Yup. So. So, yeah. I think the characterization that this would be pretty far out on the upper part of the tree, not low hanging fruit, is probably true.

-S- What about a system of airplanes talking to airplanes.

[T] Ah...

-S- In other words, you know ... usually you don't fly in a vacuum. There's somebody out there.

[T] Right. Ah, well, that's pretty much what you have today on the VHF radio comm.

-S- Mmmm hmmmm...

[T] There's very little transmission of digital data, if anything. The TCAS is one.

-S- Right.

[T] But, you know, it's only transmitting your intent.

-S- Yeah.

[T] And basically it's working on the altitude-encoding transponder.

-S- Right.

[T] The ... what ... OK ... the broadcast data bus is starting to go on that, but exactly what is transmitted is not really clear yet.

-S- Mmmm hmmmm...

[T] But, that's a different way of helping the collision system, the surveillance system, because the ones we have today can't broadcast intent. In other words, they can pretty much determine where the airplane is, somewhat crudely if all you're getting is transponder codes, ...

-S- Mmmm hmmmm...

[T] Ah, but if you tie the broadcast data system into airplane-to-airplane reception system, or simply a system that periodically goes out and said, "Here I am, I'm UAL 917, and I'm at FL240, speed, heading, stuff like that..."

-S- Mmmm hmmmm...

[T] You have a lot better location on the guy, especially with the advent of GPS systems.

-S- You could transmit some kind of coordinates, stuff like that.

[T] And pretty accurately.

-S- Yeah.

[T] So, that's possible, and there's systems that are looking to do that. I think that's going to happen. For various reasons, I think despite our improvements on the runway incursions, that's the area that I think you get the biggest bang for the buck on, because we've got a lot of traffic on those runways and when the weather goes down the guys in the tower can't really see them ...

-S- Especially at larger airports, literally you can't see them.

[T] Yeah. Right. And, so, I think something like that makes a lot of sense, but it's not there yet. There are a lot of people looking at various kinds of systems that would do that, but right now they're not out there. And, the other thing is the intent part of it. If you have a flight management system, the system is programmed to tell you ... one of the weaknesses of the TCAS system is that it's only giving you your current information, your closure rate ... you don't know that the guy's intending to level off in ten seconds ...

-S- Yeah, exactly.

[T] ... and, so, you get a false alarm.

-S- Right.

[T] And, so, you get far more false alarms than real near mid air collisions.

-S- That's one thing ... especially with the early TCAS units, they drove me nuts! You stick the stupid box in the airplane ... I spent all my time hitting "NO" ...

[T] Yeah. Right.

-S- ... and I'm not watching outside and ...

[T] Right.

-S- ... doing stuff.

[T] Right. Yup. Yeah, well, they got it ... they filtered it down with the change seven a lot, but still you're orders of magnitude from identifying real potential collisions versus ones that are not going to be a problem, so...

-S- Yeah.

[T] Because you just don't know what the intention is and whether he's going to do that or now, so the high speed verticals at the corner posts are still there as a problem.

-S- Sure.

[T] Anyway.

-S- Yeah.

[T] So, yeah, the broadcast data, I think, is real. I think the Capstone program up in ... are they using that? BSB? I don't know if that's part of what they're doing. They're using GPS. They may be using some of that. Not airplane-to-airplane, though, if anything it's a ground surveillance kind of thing, but ... but, that's certainly possible.

-S- The only reason I mention the airplane-to-airplane is thinking about if you did broadcast everything all the time, tremendous network involved. Maybe all you've got to do is just broadcast ... somebody else in the near vicinity hears it, records it, end of story.

[T] Ah, got to be able to do that. Yeah. Ah, ...

-S- Because, I think that, you know, when you look at the network required for something like this, it's not a single answer. Sometimes a satellite link is the answer.

[T] Right.

-S- Sometimes, something like that would be the answer.

[T] Right.

-S- Sometimes HF might be the answer if you're in the right place.

[T] Right.

-S- Yeah.

[T] Yeah, there is HF data links, ah ...

-S- Yeah.

[T] ... we're trying them ... trying to bring them along. I don't know, that's an area that has always been kind of intriguing, you know, people recognize that the resource is there ...

-S- Mmmm hmmmm...

[T] ... it's sort of not used. There was an effort to use the airplanes in that manner to collect weather information.

-S- Mmmm! Mmmm hmmm...

[T] It makes a whole lot of sense. You've got all these guys with sensors. They can give you ...

-S- Sure.

[T] ... temperature and wind information at all altitude levels. Never seemed to go anywhere, though.

-S- Yeah.

[T] It just couldn't get over the hurdle of "Well, what's in it for me?" kind of thing. And, ah, so, those things have not worked out too well.

-S- Well, there's technology and then there's reality.

[T] *(laughing)* Yeah.

-S- You know, we can do a lot of things, but ...

[T] ... could do it ...

-S- ... do we need to?

[T] Right. Right.

-S- I'm kind of a fan of the KISS principle.

[T] Yeah. Agree.

-S- So, I wonder if deployable units aren't the way to go. Maybe there's ... and Boeing talked about this, this morning ... where you have a recorder that's deployable and milliseconds before the flaming hole in the ground you get a little thing that pops out and it's got a, I don't know, parachute or something ...

[T] Right.

-S- Yeah. Maybe that's the infrastructure that makes sense to improve the reliability of access to the data after the crash.

[T] Yeah.

-S- I don't know.

[T] Ah, I'm trying to remember, going back ... didn't Lockheed make a recorder that was like that?

-S- Mmmm hmmmm...

[T] You know, a G-switch kind of thing ejected it in the event that you had one. I don't remember that they ever actually had an airplane accident with one of them where they actually ...

-S- I don't know of one.

[T] ... I can't remember. I don't remember one.

-S- Yeah. Well, that's were this ... the guy at L3 might be interesting because Lockheed is part of the L's there.

[T] Oh, really? *(laughing)*

-S- Yeah.

[T] OK. I started out working for Lockheed, but not that part of it. Don't know. I don't know the answer to that. The ... I don't know what you do in the deep water ones. You've got the ...

-S- Well, that's where the deployable might be nice. If you had a deployable unit that didn't sink ...

[T] Yeah.

-S- ... ah, had some sort of flotation, didn't go down with the ship kind of thing.

[T] Yeah.

-S- Yeah.

[T] Right. Might be weight and complexity and when it fires off inadvertently and all those kind of things would be a problem.

-S- Yeah, it would have to be ...

[T] Yeah.

-S- ... I can just see, you've got grandma and the kids lined up, you know, waiting for the airplane to taxi into the gate and all of the sudden this thing goes shooting out of the ...

[T] *(laughing)* Right.

-S- ... tail feathers. Yeah.

[T] Yeah.

-S- So ... well, I don't know, beyond what we've talked about, what we can hash over.

[T] OK.

-S- I guess, you know, the deeper I get into this the more I start to say, "Well, why did the FAA ask NPS to put me on this project?" because it's obvious from hundreds of pages – I've even got a thicker one than this ...

[T] Yeah.

-S- ... that it's been sliced and diced and looked at, so why is that they wanted us to do this?

[T] I don't know.

-S- I don't know, too.

[T] Yeah.

-S- I'm not sure how you got involved with this.

[T] Ah, I got a call from ... it's round about. I think, somebody at the postgraduate school called some of our R&D folks ...

-S- OK.

[T] ... and they suggested me as a contact point for you ...

-S- OK.

[T] ... and that's how I got involved in it. Yeah.

-S- Yeah.

[T] Because I'm not primarily working the recorders and stuff like that, it's more flight controls and displays and, well right now fuel tanks, but...

-S- Mmmm. OK.

[T] OK.

-S- Well then, I guess I will move forward from here.

[T] I hope it hasn't been a wasted effort for you.

-S- No, ah ...

[T] It's kind of a frustrating area, I bet. You don't know what to do.

-S- Well, it's like this. When you sign on to a thesis, sometimes the answer is yes and sometimes the answer is no, and you don't know that when you go in the front door. You say, alright, here's the question, here's the problem, let's go find out.

[T] Yeah. Well, I think that the investigation of how you could do it and what it would cost, or what you could do and what it would cost, is probably worthwhile doing.

-S- Yeah, it is.

[T] I mean, it will answer ... even a negative answer is good to know.

-S- Yeah, exactly.

[T] So...

-S- Yeah, I don't know. I mean, that's ultimately going to be the report back to ... I think it's Jim Cash? Maybe?

[T] OK. I don't know.

-S- I don't know, too, but ...

[T] OK.

-S- I should know that. I should know who our folks have talked to back there.

[T] Who requested it and you're going to ... yeah, that makes sense.

-S- But, I am getting a better picture as time goes on here and everyone adds a little bit and you have, too, so ...

[T] OK, well, good. I wish you luck with your thesis and hope it's an interesting investigation, too.

-S- I'd be happy to send you the thing when it's done. I don't imagine there's going to be any great revelations in there for you, but if you're interested ...

[T] I'm interested and I'll send it on to a couple of the guys who work recorders in D.C. and stuff like that, yeah.

-S- Whom I may run into, I don't know, I'm hoping to get back there and dig up some folks at NTSB and so on.

[T] OK, very good.

-S- Alright, thank you very much for your time.

[T] OK.

-S- Like I said, I looked you up on the Internet and I thought, Wow! This man is ...

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