Flight Test of Weather Data Exchange Using the 1090 Extended Squitter (1090ES) and VDL Mode 3 Data Links

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Abstract

This paper describes preliminary results of work done by the Weather Information Communications (WINCOMM) project at the NASA Glenn Research Center to support flight testing of the 1090 Extended Squitter (1090ES) and VDL Mode 3 data links as a medium for weather data exchange. It presents a high level architectural description of the use of 1090ES to meet the program objectives of sending turbulence information and the use of VDL Mode 3 to send graphical weather images. This report will identify issues associated with the use of these data links, including a high level definition of the changes required to both avionics and ground-based receivers as well as the ground infrastructure to support implementation of the recommended architecture, with a focus on the issues associated with these changes.

1 Introduction

The goal of WINCOMM [1] is to develop advanced communications and information technologies to enable the high quality and timely dissemination of strategic weather information between the flight deck and ground users and tactical turbulence hazard information between relevant aircraft. The specific goal of the Commercial Transport task area [2] is to develop a weather dissemination capability for commercial transport aircraft within a national network that includes:

- On-board sensed turbulence information to ground users and between aircraft. (air-ground, air-air)
- Broadcast graphical weather products to the pilot. (ground-air)

The objective of the Commercial Transport task area is to demonstrate a path to implementation for the following value added objectives:

- Dissemination of data from own ship turbulence events to other aircraft and ground users.
- Receive, process and deliver valid turbulence warnings to the cockpit from other equipped aircraft.
- Receive and display Flight Information Service Broadcast (FIS-B) ground-air weather products.

This paper first presents the architecture developed by the WINCOMM project for communication of weather data information to commercial transport aircraft. Next, the datalinks are described individually, and finally a description of the planned laboratory and validation flight tests are outlined.

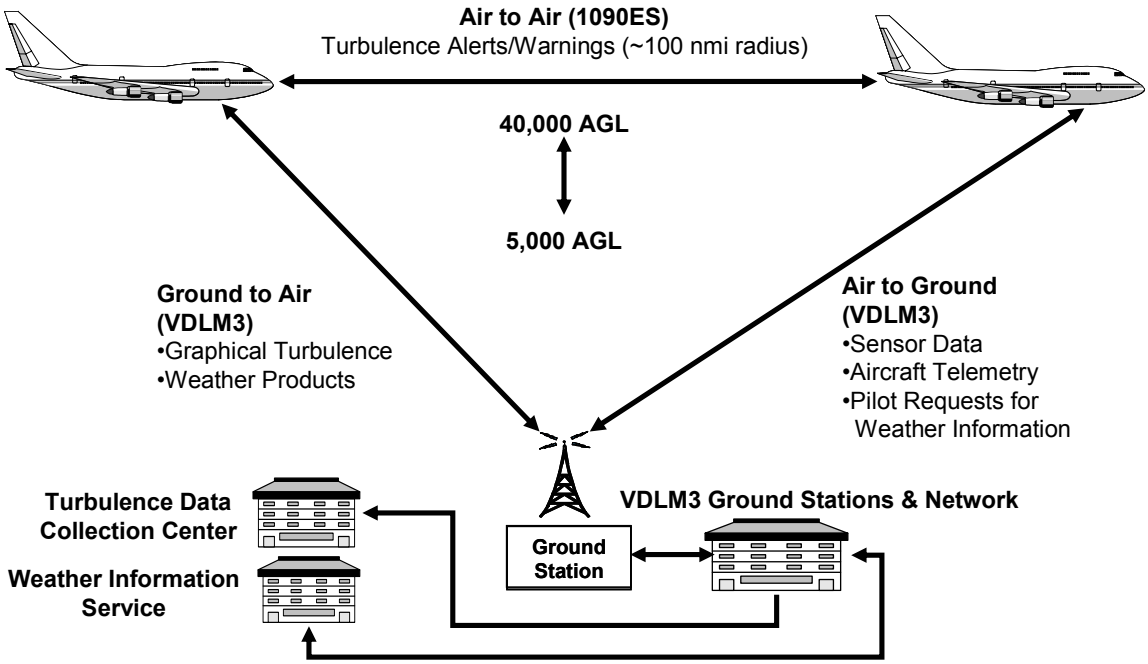

Figure 1: Overall Commercial Transport Architecture

2 Architecture

Due to the near-term focus of the WINCOMM project it was necessary to select datalinks that already reside on commercial transport aircraft or were on a path for installation in the near future. No single datalink can currently satisfy the project requirements for air-to-air, ground-to-air broadcast, and air-to-ground two-way communication to this class of aircraft. It was therefore necessary to design a hybrid communication architecture, as shown in Figure 1. For air-to-air communication, the 1090 Extended Squitter (ES) datalink [3] was selected to transmit own ship turbulence events to other aircraft, and to receive turbulence warnings from other aircraft. VDL Mode 3 [4] was selected for transmission of own ship turbulence events to ground users, and for ground-air transmission of FIS-B weather products.

3 Datalinks

3.1 1090ES

In order to send broadcast turbulence messages between commercial transport aircraft, a datalink capable of air-to-air communication was necessary. A natural match for this communication is one of the Automatic Dependent Surveillance Broadcast (ADS-B) links. On July 1, 2002, the FAA announced the ADS-B link decision [5], which was a combination of the 1090ES link for air carrier and private/commercial operators of high performance aircraft, and the Universal Access Transceiver (UAT) link for the typical general aviation user.

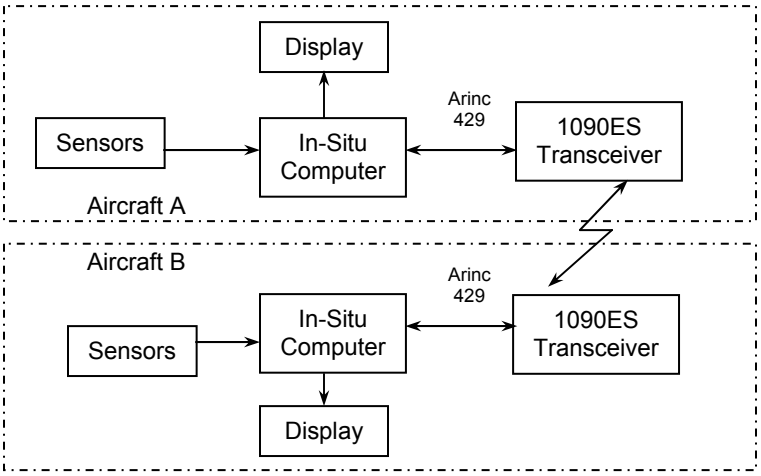

Figure 2: 1090ES Data Flow

3.1.1 1090ES Turbulence Alert Message

The turbulence alert message will consist of the following parameters:

1. Time
2. Latitude
3. Longitude
4. Altitude
5. Processed Normal Load
6. Processed Aircraft Constant

Since standard ADS-B messages already contain the first four parameters, it is only necessary to broadcast two additional parameters. These two additional parameters are each eight bits long, totaling an additional 16 bits to be transmitted. The additional parameters will be formatted as a payload to a standard ADS-B message, in compliance with DO–260A.

The turbulence alert message is transmitted only when one of three thresholds is exceeded and repeated only if the threshold is maintained for a set interval (currently 30 seconds). This intermittent transmission should not pose a significant load increase for the 1090ES ADS-B link [6].

3.1.2 Data Flow

The data flow for the messages over 1090ES is shown in Figure 2. When the turbulence algorithms in the In-Situ computer issues a turbulence alert message, the message is sent via an ARINC 429 bus to the 1090ES transceiver for transmission. The 1090ES transceiver transmits the turbulence alert message interleaved with the standard ADS-B messages. The message can be received by any aircraft appropriately equipped with a 1090ES transceiver capable of receiving at 1090MHz, and within range of the transmitting aircraft. The ADS-B turbulence alert message is received by the 1090ES transceiver, which forwards it to the In-Situ computer for processing. Algorithms in the In-Situ computer determine the effect the received turbulence level will have on the receiving aircraft, and issues the processed alert to the pilot.

3.2 VDL Mode 3

In order to transmit reliable turbulence messages to the ground, and to broadcast FIS-B graphical weather images from the ground to multiple aircraft, a bi-directional datalink was necessary. The two bi-directional datalinks on the horizon for near-term use are

VDL Mode 2 and VDL Mode 3. Since VDLM3 uses a Time Division Multiple Access (TDMA) Differential – 8 Phase Shift Keying (D8PSK) modulation scheme, this allows a number of users to access a single Radio Frequency (RF) channel by dividing a single 25 kHz channel into four time slots and allocating each time slot to one user/application. The channel separation can be utilized to effectively separate non-critical data, weather information, from critical data, Controller Pilot DataLink Communication (CPDLC). VDL Mode 3 was also designed with a ground broadcast mode, which will facilitate FIS-B communications.

3.2.1 VDL Mode 3 Messages

3.2.1.1 Turbulence Message

The turbulence message will consist of the following parameters:

1. Time
2. Latitude
3. Longitude
4. Altitude
5. Aircraft Weight
6. Airspeed
7. Mach Number
8. Processed Normal Load
9. Processed Aircraft Constant

Additional parameters are required beyond those in the turbulence alert message, to allow ground processing of the downlinked messages to be assimilated into weather prediction models and a national turbulence weather product.

3.2.1.2 Weather Product Request Message

In order to allow pilots to request graphical weather products which may not be part of the standard weather product set, described below in Section 3.2.1.3, a request message will be transmitted to schedule the uplink of the desired product. The final format of this message has not been defined.

3.2.1.3 FIS-B Messages

For the purposes of the WINCOMM project, the broadcast FIS-B messages will, at a minimum, consist of the following weather products:

1. Text Products
   - METARs
   - TAFs
   - PIREPs
   - AIRMETs
   - SIGMETs
   - Convective SIGMETs
   - Alert Weather Watches
2. National NEXRAD
3. Graphical AIRMETs
4. Graphical SIGMETs
5. Graphical Convective SIGMETs
6. Graphical Alert Weather Watches
7. Graphical METARs

In addition to these standard products, the pilot requested messages, as described above in Section 3.2.1.2, will be transmitted as requested and as the channel is available.

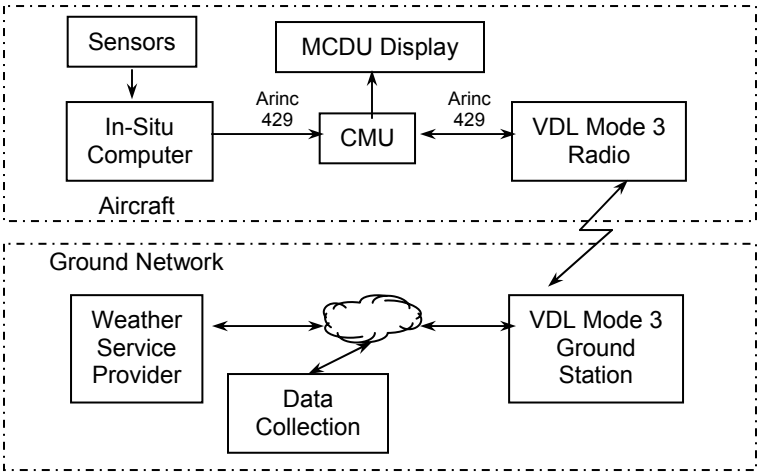

Figure 3: VDL Mode 3 Data Flow

3.2.2 Data Flow

The detailed data flow of messages over VDL Mode 3 is shown in Figure 3.

3.2.2.1 Turbulence Downlink Message

An In-Situ computer is used to process sensor data and generate a turbulence downlink message. The turbulence downlink message is sent via an ARINC 429 interface into the Communications Management Unit (CMU) for encapsulation into a TCP/IP packet and routed to the VHF Digital Radio (VDR) for transmission. The VDR transmits the turbulence downlink message according to VDL Mode 3 specifications. The message is received by the VDL Mode 3 ground station and is routed to a weather data collection facility.

3.2.2.2 Weather Product Request Message

A pilot chooses a weather product from a menu in the cockpit Multifunction Control and Display Unit (MCDU). This action results in a TCP/IP message being generated in the CMU specifying the desired weather product. The CMU routes this message through the VDR for transmission to the ground station. The ground station routes the request message to the weather service provider for product generation. The weather service provider will generate the specified weather product, as necessary, and route it to the appropriate ground station for broadcast. This weather product will be transmitted for a specified length of time, to allow reception by the requesting aircraft as well as other aircraft in reception range of the transmitting ground station. This requested product will be transmitted at a lower priority than the standard weather products, described in Section 3.2.1.3.

The business case for sending these additional products is outside the scope of this project. The broadcasting of these messages does not necessarily mean that all aircraft would be able to view the images. The messages in all cases may be encrypted to allow only those with the proper key to decode and display the images. This encryption would be left to the final implementation of the system and is not within the scope of this project.

3.2.2.3 FIS-B Messages

A weather service provider generates the specified weather products at designated product intervals and routes these products to

the ground station for transmission. The ground station interleaves the standard products with the additional requested messages and transmits the messages at a specified interval. The aircraft's VDR receives the FIS-B messages, which are routed to the CMU for processing. The CMU assembles the messages into viewable graphical images. When the pilot requests a weather product from the MCDU, the latest version of the image stored in the CMU is shown.

4 Laboratory Testing

Laboratory testing of the datalinks will concentrate on the implementation of the additional messages transmitted, as described in Section 3, and the associated equipment software modifications. Limited testing will also be conducted on the existing radio/transceiver operation. Extensive testing of both datalinks has been completed by the FAA [7][8], which does not bear repeating.

4.1 1090ES

Two complete sets of 1090ES equipment, representing two aircraft, will be tested back-to-back using appropriate attenuation. A pre-recorded data file will be used to simulate inputs to the In-Situ computer, in order to exercise the turbulence algorithms. Data files will be collected on both aircraft racks to verify transmission and reception of turbulence alert messages. Limited attenuation profiles will be utilized to represent the experimental flight campaign.

Traffic on 1090MHz, beyond the ADS-B message emanating from the two aircraft, will not be emulated during testing. The ability to transmit the additional turbulence alert ADS-B messages at 1090MHz has been shown to work in simulations [6], and will not be tested with other traffic until flight tests are conducted.

4.2 VDL Mode 3

One set of VDL Mode 3 avionics will be tested against an FAA ground station. This will either be through an attenuation scheme similar to the 1090ES laboratory testing, or through an antenna-based method. A pre-recorded data file will be used to simulate inputs to the In-Situ computer, in order to exercise the turbulence algorithms. A group of pre-generated FIS-B weather products will be used to feed the ground station, during testing. This group of products will include both standard broadcast messages as well as pilot requested messages. Data files will be collected on both sides to determine message transmission and reception.

5 Flight Testing

As in the laboratory experiments, testing the datalinks will concentrate on the implementation of the message changes made by the project, and will include limited testing of existing radio/transceiver operation.

5.1 1090ES

Flights will be conducted in a convenient area of the continental U.S., as determined by the spectrum approval of the FAA. No turbulence encounters will be sought out. Turbulence alert test messages will be transmitted in order to effectively utilize flight time. The flights will consist of flying two aircraft at various ranges in order to perform limited testing of effective reception of turbulence alert messages. Data files will be collected on both aircraft racks to verify transmission and reception of turbulence alert messages.

5.2 VDL Mode 3

Flights will be conducted in an area near an

FAA VDL Mode 3 ground station. As in the 1090ES flight tests, no turbulence encounters will be sought out. Turbulence alert test messages will be transmitted in order to effectively utilize flight time. Pilot weather product request messages will be transmitted from the aircraft. Standard FIS-B as well as pilot requested weather products will be broadcast to the aircraft. The flights will consist of flying one aircraft at various ranges and altitudes from the ground station in order to perform limited testing of effective reception of turbulence downlink and FIS-B messages. Data files will be collected on both sides to determine message transmission and reception.

6 Conclusions

This paper outlines the modifications necessary to transmit and receive weather related messages to and from commercial transport aircraft. All equipment modifications will be software based in order to allow the reception and transmission of these additional messages. All modifications will be made within the accepted standards or in a manner consistent with the standards. These changes are being worked closely with industry partners with a path toward certification.

References

[1] WINCOMM Project Homepage, http://wincomm.grc.nasa.gov

[2] Jarrell, M., "Preliminary Datalink Architectures for the Flight Demonstration of Weather Dissemination Technologies," NASA Document, February 2004

[3] RTCA/DO–260A, "Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance—Broadcast (ADS–B) and Traffic Information Services—Broadcast (TIS–B)," April 10, 2003

[4] RTCA/DO-279, "Next Generation Air/Ground Communications (NEXCOM) Principles of Operations VDL MODE 3," March 5, 2002

[5] Jones, T., "FAA Announces Automatic Dependent Surveillance-Broadcast Architecture," FAA Press Release APA 27-02, July 1, 2002

[6] Johns Hopkins 1090 simulations, to be released as NASA documents

[7] Morgenstern, R., "VDL Mode 3 flight Test Report 2," MITRE Document MP 00W0000008, January 2000

[8] ADS-B Technical Link Assessment Team (TLAT), "Technical Link Assessment Report," March 2001

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ICNS Briefing

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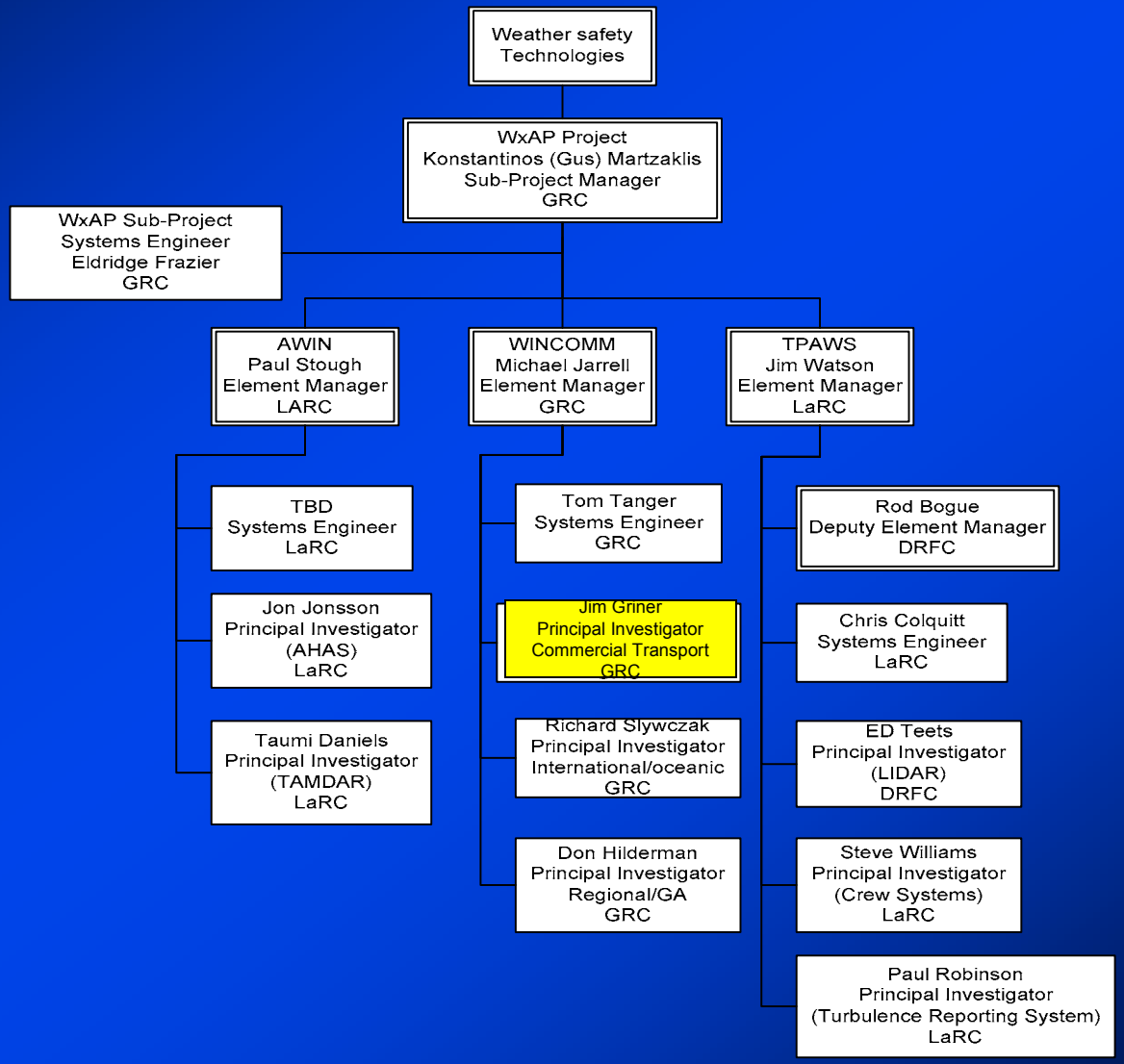
Organization

WINCOMM **Glenn Research Center**



Commercial Transport Goal

The specific goal of the Commercial Transport task area is to develop a weather dissemination capability for commercial transport aircraft within a national network that includes:

- Transmission of on-board sensed turbulence information to ground users and between aircraft.
- Broadcast graphical weather products to the pilot.

Architecture Design

- Due to the near-term focus of the WINCOMM project it was necessary to select datalinks that already reside on commercial transport aircraft or were on a path for installation in the near future.

- No single datalink can currently satisfy the project requirements for air-to-air, ground-to-air broadcast, and air-to-ground two-way communication to this class of aircraft. It was therefore necessary to design a hybrid communication architecture to meet the project objectives

Objectives

Demonstrate a path to implementation for the following value added objectives:

- Dissemination of data from own ship turbulence events to other aircraft and ground users.
- Receive, process and deliver valid turbulence warnings to the cockpit from other equipped aircraft.
- Receive and display Flight Information Service Broadcast (FIS-B) ground-air weather products.

Objectives 1&2

added objectives:

- Dissemination of data from own ship turbulence events to other aircraft and ground users.

- Receive, process and deliver valid turbulence warnings to the cockpit from other equipped aircraft.

Need an Air-to-Air link

Air-to-Air

A natural match for air-to-air communication is one of the Automatic Dependent Surveillance Broadcast (ADS-B) links.

- On July 1, 2002, the FAA announced the ADS-B link decision [5], selecting the 1090 Extended Squitter link for air carrier and private/commercial operators of high performance aircraft

1090ES datalink was selected by WINCOMM to fulfill the air-to-air datalink requirements for the transmission of turbulence alerts.

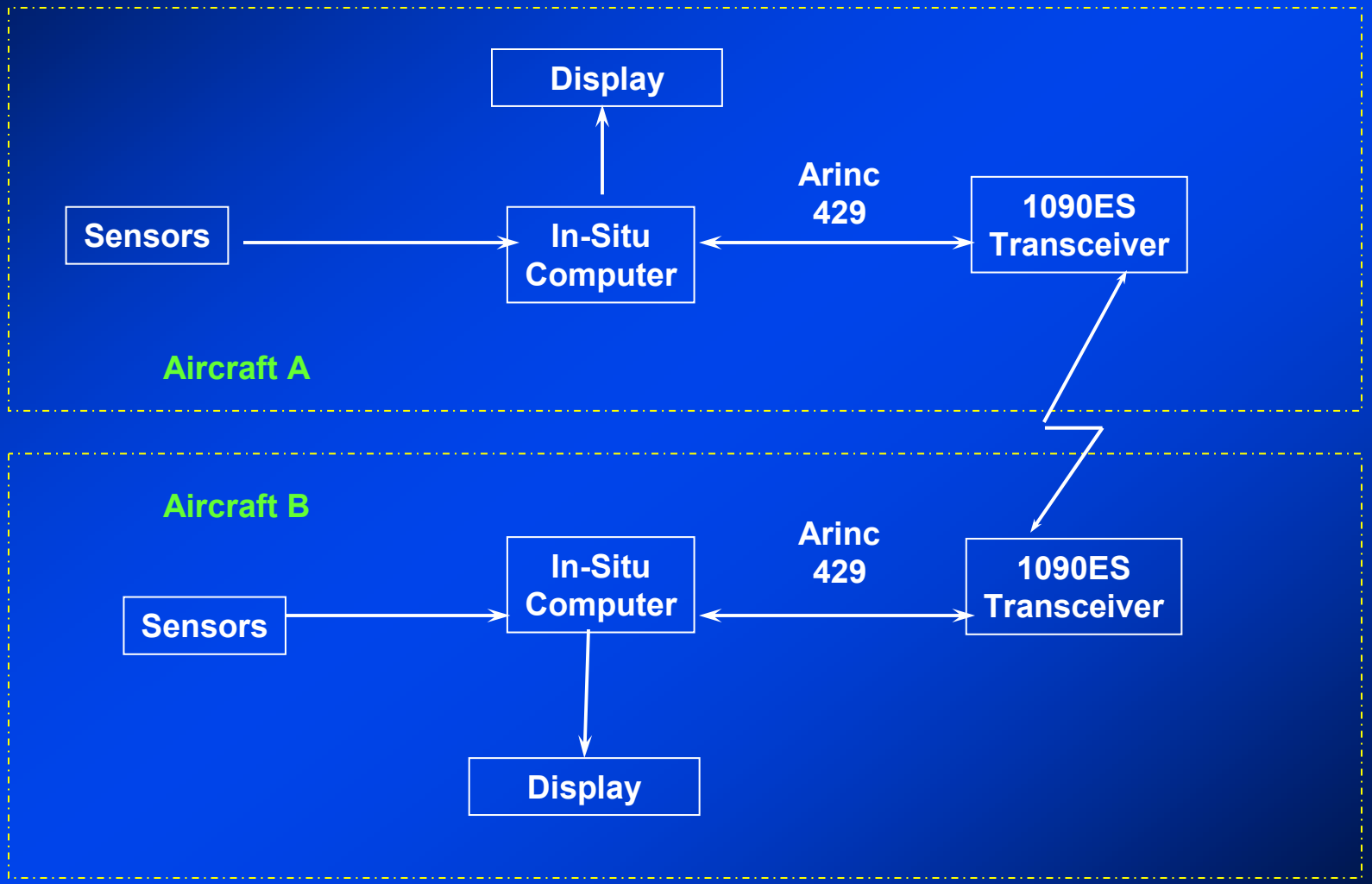
Turbulence Alert Message

- The turbulence alert message will consist of the following parameters:

1. Time
2. Latitude
3. Longitude
4. Altitude
5. Processed Normal Load
6. Processed Aircraft Constant

- Standard ADS-B messages already contain the first four parameters, it is only necessary to broadcast two additional parameters. These two additional parameters are each eight bits long, totaling an additional 16 bits to be transmitted. The additional parameters will be formatted as a payload to a standard ADS-B message, in compliance with DO–260A.

1090ES Data Flow



Lab Testing in General

- Laboratory testing of the datalinks will concentrate on the implementation of the additional messages transmitted and the associated equipment software modifications.

- Limited testing will be conducted on the existing radio/transceiver operation.

- Extensive testing of the datalinks have been completed by the FAA, which does not bear repeating.

1090ES Lab Testing

- Two complete sets of 1090ES equipment, representing two aircraft, will be tested back-to-back using appropriate attenuation.

- A pre-recorded data file will be used to simulate inputs to the In-Situ computer, in order to exercise the turbulence algorithms.

- Data files will be collected on both aircraft racks to verify transmission and reception of turbulence alert messages.

- Limited attenuation profiles will be utilized to represent the experimental flight campaign.

1090ES Lab Testing

- Traffic on 1090MHz, beyond the ADS-B message emanating from the two aircraft, will not be emulated during testing.

- The ability to transmit the additional turbulence alert ADS-B messages at 1090MHz has been shown to work in simulation, and will not be tested with other traffic until flight tests are conducted.

1090ES Flight Testing

- Flights will be conducted in a convenient area of the continental U.S., as determined by the spectrum approval of the FAA.

- No turbulence encounters will be sought out. Turbulence alert test messages will be transmitted in order to effectively utilize flight time.

- The flights will consist of flying two aircraft at various ranges in order to perform limited testing of effective reception of turbulence alert messages.

- Data files will be collected on both aircraft racks to verify transmission and reception of turbulence alert messages.

Objective 1&3

added objectives.

- Dissemination of data from own ship turbulence events to other aircraft and ground users.
- Receive and display Flight Information Service Broadcast (FIS-B) ground-air weather products.

- This objective requires at a minimum a ground-to-air broadcast link. WINCOMM's experiments will also include an air-to-ground request message, in order to facilitate the broadcast of additional value-added weather products, and a reliable air-ground turbulence alert message.

- With the additional requirements we now need a *bi-directional air-to ground datalink.*

Bi-Directional Air-Ground link

The two bi-directional datalinks on the horizon for near-term use are VDL Mode 2 and VDL Mode 3.

- VDLM3 uses a Time Division Multiple Access (TDMA) scheme, which allows a number of users to access a single Radio Frequency (RF) channel by dividing a 25 kHz channel into four time slots and allocating each time slot to one user/application. The channel separation can be utilized to effectively separate non-critical data, weather information, from critical data, Controller Pilot DataLink Communication (CPDLC).
- VDL Mode 3 was designed with a ground broadcast mode, which will facilitate FIS-B communications.

VDL Mode 3 Messages

- Reliable Air-ground turbulence messages
- Reliable Air-ground message for requesting additional graphical weather products
- Broadcast Ground-Air FIS-B weather products

Air-Ground Turbulence Message

- The turbulence message will consist of the following parameters:

1. Time
2. Latitude
3. Longitude
4. Altitude
5. Aircraft Weight
6. Airspeed
7. Mach Number
8. Processed Normal Load
9. Processed Aircraft Constant

- Additional parameters are required beyond those in the turbulence alert message, to allow ground processing of the downlinked messages to be assimilated into weather prediction models and a future national turbulence weather product.

Air-Ground Request Message

- In order to allow pilots to request graphical weather products which may not be part of the standard weather product set, a request message will be transmitted to schedule the uplink of the desired product.

- The final format of this message has not been defined.

Ground-Air Weather Products

- For the purposes of the WINCOMM project, the broadcast FIS-B messages will, at a minimum, consist of the following weather products:

1. Text Products
   - METARs
   - TAFs
   - PIREPs
   - AIRMETs
   - SIGMETs
   - Convective SIGMETs
   - Alert Weather Watches
2. National NEXRAD
3. Graphical AIRMETs
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5. Graphical Convective SIGMETs
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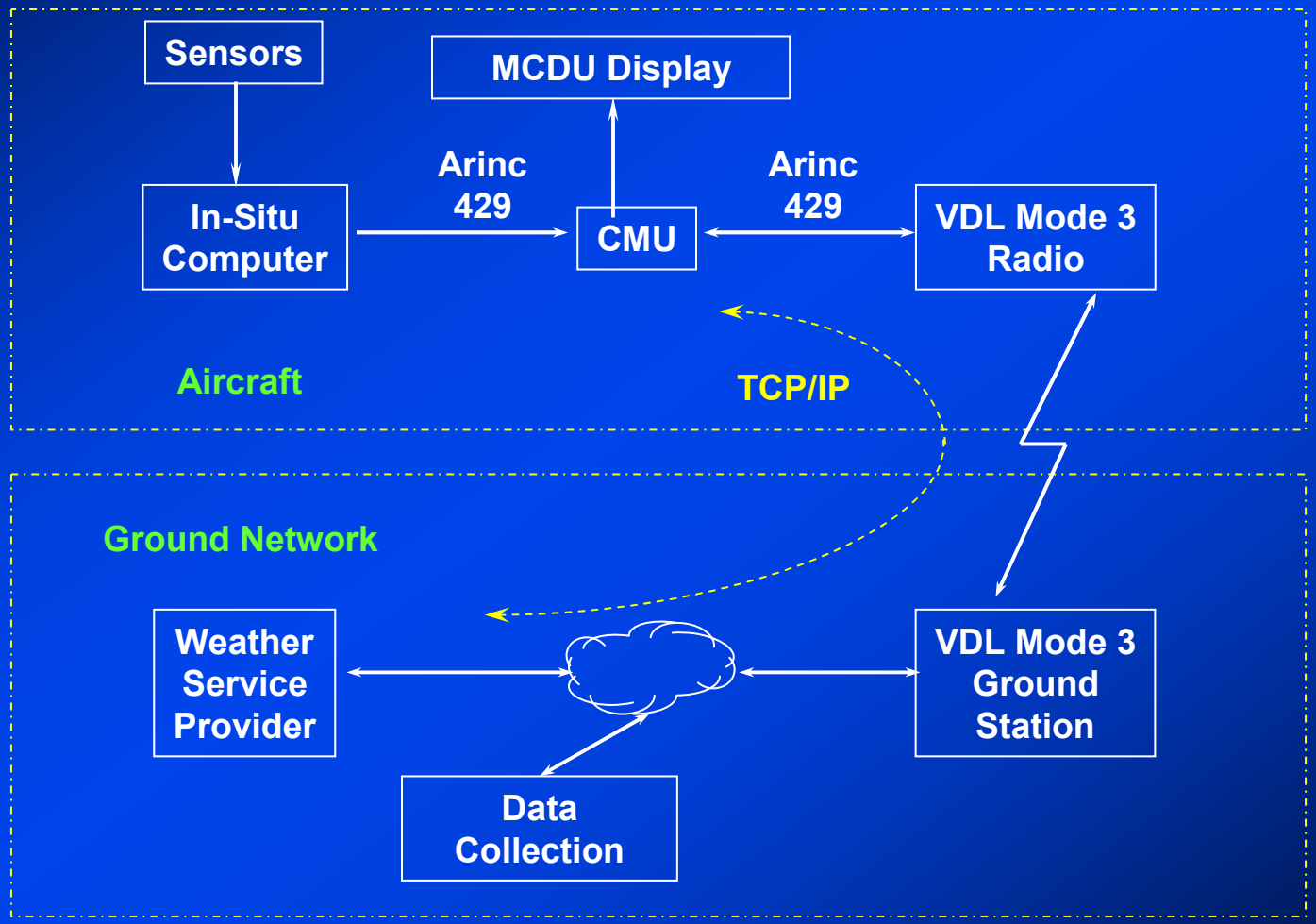
- In addition to these standard products, the pilot requested messages will be transmitted as requested and as the channel is available

VDL Mode 3 Data Flow



VDL Mode 3 Lab Testing

- One set of VDL Mode 3 avionics will be tested against an FAA ground station. This will either be through an attenuation scheme similar to the 1090ES laboratory testing, or through an antenna-based method.

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- A group of pre-generated FIS-B weather products will be used to feed the ground station, during testing. This group of products will include both standard broadcast messages as well as pilot requested messages.

- Data files will be collected on both sides to determine message transmission and reception.

VDL Mode 3 Flight Testing

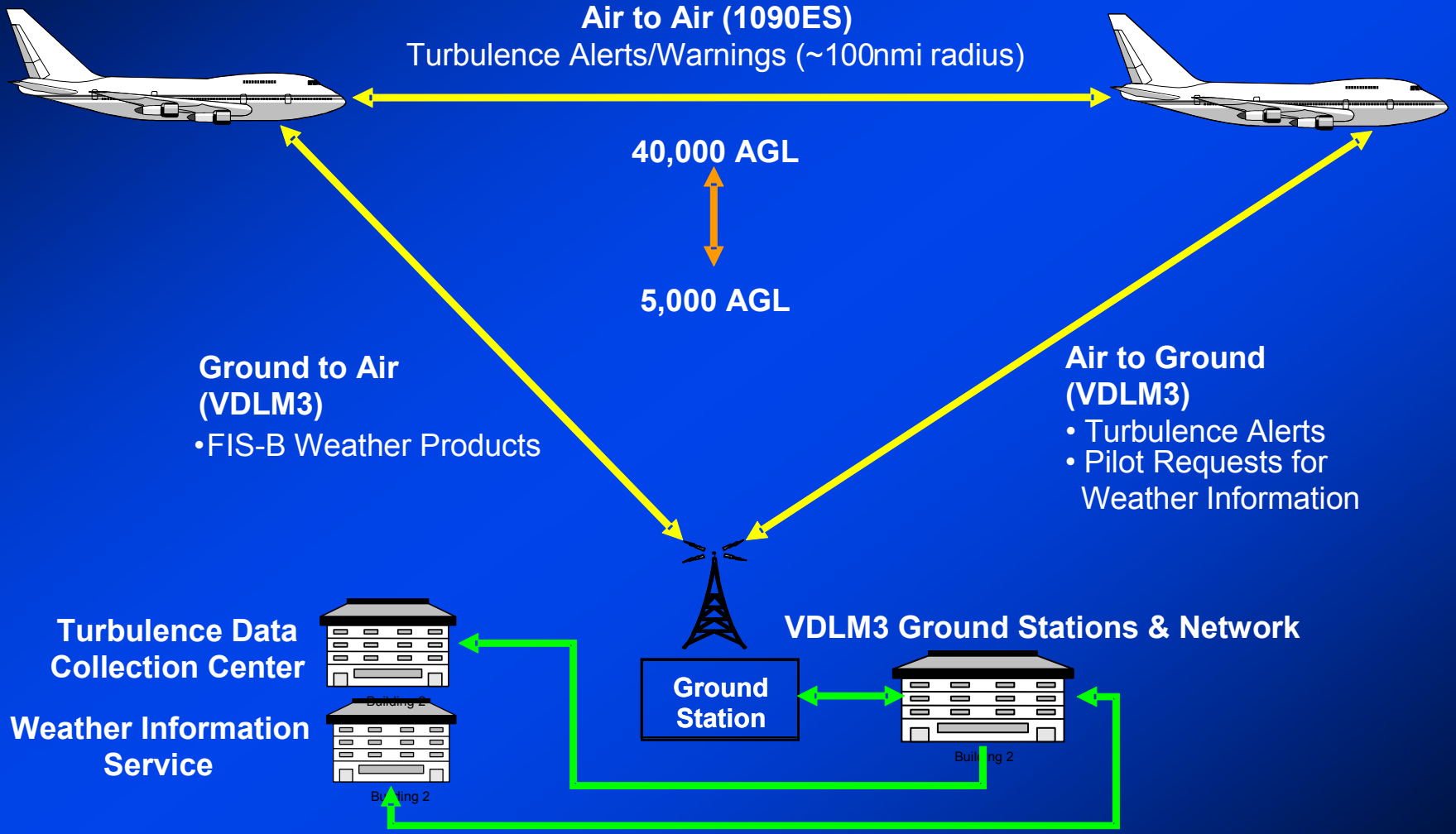
- Flights will be conducted in an area near an FAA VDL Mode 3 ground station.
- No turbulence encounters will be sought out.
- Turbulence alert test messages will be transmitted in order to effectively utilize flight time.
- Pilot weather product request messages will be transmitted from the aircraft.
- Standard FIS-B as well as pilot requested weather products will be broadcast to the aircraft.

VDL Mode 3 Flight Testing

- The flights will consist of flying one aircraft at various ranges and altitudes from the ground station in order to perform limited testing of effective reception of turbulence downlink and FIS-B messages.

- Data files will be collected on both sides to determine message transmission and reception.

Overall Architecture



Summary

- All equipment modifications will be software based in order to allow the reception and transmission of these additional messages.

- All modifications will be made within the accepted standards or in a manner consistent with the standards.

- These changes are being worked closely with industry partners with a path toward certification.