Compatibility of Weather Avoidance Trajectories with Datalink

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This paper examines the feasibility of using datalink communication for convective weather reroutes in the National Airspace System. Flight trajectories from a day in 2006 were surveyed for weather avoidance re-routes, and those route amendments were assessed to determine the proportion that could be satisfied by existing Controller-Pilot Data Link Communication protocols and the number of datalink messages needed to satisfy the clearance issued. All 753 clearances could be described by a datalink message. The messages were grouped into four categories: deviation, heading, route clearance, and offset. Fifty-two percent of the weather avoidance maneuvers were satisfied by a deviation message. Deviation datalink messages are easy to load, send, and receive for both the controller and pilot. Some form of a heading message satisfied 25% of the clearances, and 17% could be described by a route clearance message. The remaining 6% were satisfied by an offset. The results identify the specific datalink messages that should be considered in the development of weather avoidance automation.

I. Introduction

WEATHER is the most significant contributing factor to delays in the National Airspace System (NAS).[1] Seventy percent of delays are weather-induced, with sixty percent caused by convective weather. Convective weather places an incredible strain on the air traffic control system, and weather avoidance is an important part of NAS operations. With expectations of increased traffic demand in the coming years, the weather avoidance problem will only get worse and delays will continue to increase.[2, 3] NASA is researching trajectory based automation concepts and technology including higher levels of automation for separation assurance and traffic flow management functions to reduce controller workload and accommodate the expected steady rise in air traffic demand. [3,4] Four-dimensional modeling and analysis of aircraft trajectories and air/ground datalink communications are expected to be key elements of a Next-Generation Air Transportation System.[3, 5] In today's operations, pilots request weather avoidance routes by voice, and controllers coordinate weather avoidance reroutes by voice. Convective weather avoidance must be a key component of any trajectory-based automation system for the NAS.

The Controller–Pilot Data Link Communication (CPDLC) program was designed to enable digital communication between the pilot and controller.[6] By increasing the number of CPDLC-equipped aircraft, there is expected to be a reduction in controller workload and time devoted to voice communications, enabling an increase in sector capacity.[3,7] Past simulations have shown the benefits and efficiency of datalink.[8,9] While several research simulations have proven the feasibility of communicating trajectories via CPDLC,[10,11] and a 2008 simulation demonstrated that CPDLC can be used for weather avoidance,[12] the literature has not assessed the proportion of weather avoidance maneuvers that can/cannot be communicated via CPDLC. The present study responds to this question with an analysis of real-world operational data.

This study examines 753 flights that were rerouted around weather to determine how many of the route amendments could be described in a datalink message and what datalink message types would be needed to satisfy the reroutes. The methodology is described in the next section. Section III presents an example from each category of datalink message along with a possible datalink communication exchange that could have satisfied the trajectory amendment. The results section presents the findings and summarizes their significance.

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II. Methodology

The study relied upon traffic surveillance data, flight plan data and weather information, all recorded from live operations on July 14, 2006. This date was chosen because it was a particularly bad weather day for the NAS. As shown in figure 1, the convective weather was over the eastern part of the United States. The weather contains multiple cells of convection. This would affect many flights and yield numerous flight modifications that could be analyzed. The data recording was an eight-hour period that night. Over 750 flights were extracted by looking for flight plans that were affected by the areas of convection. The Convective Weather Avoidance Model (CWAM) was used to construct a three-dimensional model of the convective constraints, which analysis software could then screen for intersections of flight plans and CWAM probability contours.[13] The probability contours identified regions predicted to have equal probability of a flight plan deviation to avoid convective weather.[14] For example, in figure 1, pink regions represent a 60% probability that a pilot would avoid that area due to weather. For specified flight level and probability, the analysis software identifies the relevant flights and generates pictures such as figure 3 showing the original flight plan, the contours that the pilot is expected to avoid, and the actual flight plan modification used to avoid the convective area. This research examined flights between FL250 and FL450 at probabilities of deviation between 40 and 80%. More information about CWAM can be found in DeLaura and Evans [Ref 14].

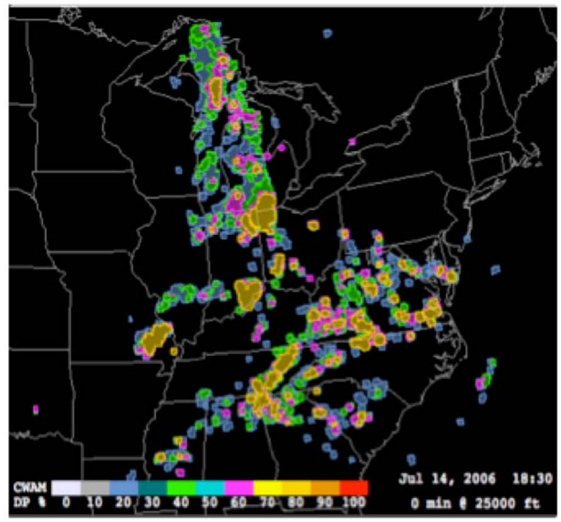

Figure 1: CWAM Probability Contour at 25000 ft

By human inspection, each flight modification was analyzed to determine if the resulting route amendment could have been communicated via CPDLC. The list of CPDLC messages contains 182 uplink messages (UM) and 80 downlink messages (DM). Uplink messages are sent from the ground up to the aircraft, and the downlink messages are sent from the aircraft down to the ground. Since some pilots may be more accepting of adverse weather than others[16] and deviations for weather are typically the responsibility of the flight crew, it will be assumed that future use of datalink communications for weather re-routes will be initiated by the flight crew (i.e., will be initiated with a downlink message).

III. Controller–Pilot Data Link Communication Messages

While the CPDLC protocol contains 262 message types, those relevant to the results of this particular study fall into four categories: heading messages, offset messages, route-clearance messages, and deviation messages, A short definition of each is provided below, along with a template of most of the datalink messages that satisfy the category and a schematic. These categories describe what the pilot did to avoid the convective weather. The numbers indicate the type of message, and the information to be communicated is specified inside the brackets.

A **heading message** tells the pilot in what direction to point the aircraft. The heading category also includes the "direct to" messages. Figure 2a is an illustration of a heading.

Downlink messages:

DM22 – REQUEST DIRECT TO [POSITION]
DM70 – REQUEST HEADING

Uplink messages:

UM74 – PROCEED DIRECT TO [POSITION]
UM76 – AT [POSITION] PROCEED DIRECT TO [POSITION]
UM96 – FLY PRESENT HEADING
UM97 – AT [POSITION] FLY HEADING [DEGREES]

The intent for an **offset message** is to fly a fixed lateral distance parallel to the original route clearance. For example, when the original route turns 25˚ from one waypoint to the next, the offset route mimics the 25˚ turn. The offset distance and direction must be specified. The pilot must be given the point at which the aircraft is to return to the original route. Figure 2b depicts an offset.

Downlink messages:

DM15 – REQUEST OFFSET [DISTANCE] [DIRECTION] OF ROUTE

DM16 – AT [POSITION] REQUEST OFFSET [DISTANCEOFFSET] [DIRECTION] OF ROUTE

DM17 – AT [TIME] REQUEST OFFSET [DISTANCEOFFSET] [DIRECTION] OF ROUTE

Uplink messages:

UM64 – OFFSET [DISTANCEOFFSET] [DIRECTION] OF ROUTE

UM65 – AT [POSITION] OFFSET [DISTANCEOFFSET] [DIRECTION] OF ROUTE

UM66 – AT [TIME] OFFSET [DISTANCEOFFSET] [DIRECTION] OF ROUTE

A **route clearance message** allows for a more precise route to be communicated and is formatted to facilitate easy entry into the flight management system (FMS) of FANS 1/A-equipped aircraft. This is only a small percentage of aircraft that are currently flying. By having the flexibility of being able to receive an uplink message, a very detailed message could be communicated to the pilot from the ground. Pilots of aircraft that are not equipped with FANS 1/A would have to manually enter the uplinked route clearance into the FMS, a time-consuming and tedious task. A route clearance message conveys modifications to the filed route. Pilots can simply request a clearance or can downlink a specific series of waypoints, navigation aids, or jet routes that they would like to fly. Figure 2c is an example of a route clearance.

Downlink messages:

DM23 – REQUEST [PROCEDURENAME]

DM24 – REQUEST [ROUTECLEARANCE]

DM25 – REQUEST CLEARANCE

Uplink messages:

UM79 – CLEARED TO [POSITION] VIA [ROUTECLEARANCE]

UM80 – CLEARED TO [ROUTECLEARANCE]

UM83 – AT [POSITION] CLEARED [ROUTECLEARANCE]

UM84 – AT [POSITION] CLEARED [PROCEDURENAME]

A **deviation message** conveys a less-constrained maneuver as compared to the previous three. Pilots can request a distance and direction that is needed to deviate around or between storms. The pilot is permitted to fly anywhere within the specified distance from the current route, and the direction can be on one or either side of the current flight plan. This category offers the pilot flexibility in choosing where to fly and maneuver around convective areas. An example of a deviation is shown below in Figure 2d.

Downlink messages:

DM25 – REQUEST CLEARANCE

DM26 – REQUEST WEATHER DEVIATION TO [POSITION] VIA [ROUTECLEARANCE]

DM27 – REQUEST WEATHER DEVIATION UP TO [POSITION] VIA [ROUTECLEARANCE]

Uplink messages:

UM82 – CLEARED TO DEVIATE UP TO [DISTANCEOFFSET] [DIRECTION] OF ROUTE

Lastly, to offer a complete datalink communication solution to the voice channel, a few other datalink messages would have to be included. A common feedback from pilots that participate in simulations with the use of datalink is that they want to know the reason behind a given clearance change that is directed by the controller.[17] For any clearance, the pilot wants two pieces of information for when a clearance is issued: reason for the deviation and how to get back on route. There are several uplink messages the controller can send that will inform the pilot of these essential details. The controller also has the flexibility to send any message that does not have a defined format with the freetext message, UM 169. Examples are shown below.

Downlink messages:

(not applicable)

Uplink messages:

UM68 – REJOIN ROUTE BY [POSITION]

UM70 – EXPECT BACK ON ROUTE BY [POSITION]

UM79 – CLEARED TO [POSITION] VIA [ROUTECLEARANCE]

UM169 – [FREETEXT]

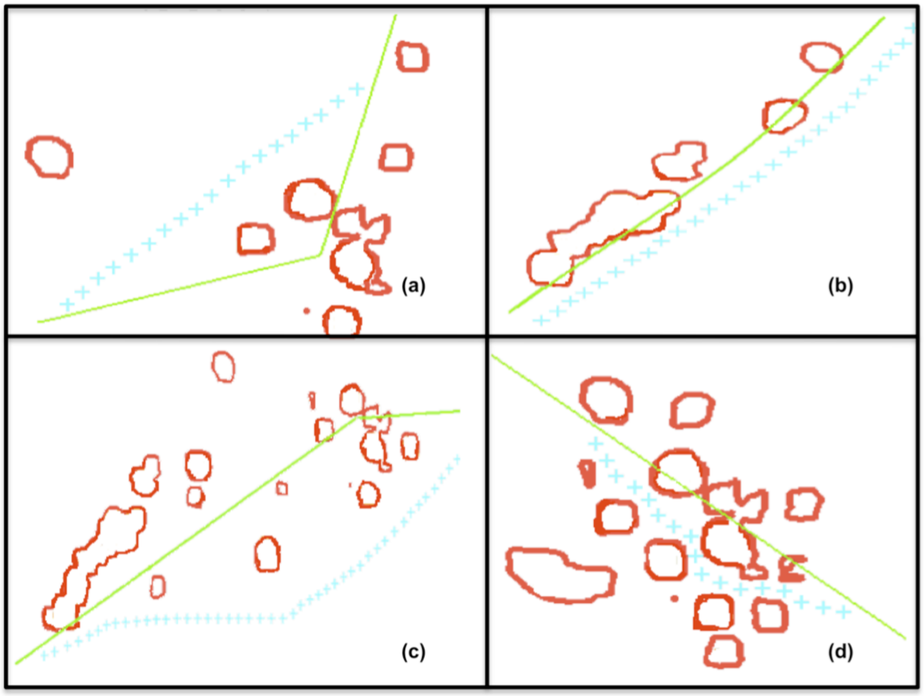

Figure 2. (a) heading, (b) offset, (c) route clearance, (d) deviation. The blue crosses represent the actual track the aircraft flew, the green line represents the filed flight plan, and the red polygons represent the 80% CWAM probability contour.

IV. Example Weather Avoidance Maneuvers and Supporting Datalink Messages

An actual weather avoidance trajectory modification from each category will be shown along with an example of the datalink messages that could have been exchanged to satisfy the actions taken by the pilot and controller. In each figure, a green line indicates the filed flight plan, blue crosses represent the clearance that was issued, red polygons depict the 80% CWAM probability contour, and small pink circles track the actual path flown by the aircraft. The names of the relevant jet routes, waypoints, and navigation aids are displayed. A brief description of the situation, an image of the flight data, and the datalink transactions that would satisfy the clearance issued are listed below for each category.

A. Deviation

AC1 is flying southwest to Houston, Texas from Raleigh, North Carolina. There is convective weather that will interfere with the filed flight plan shown in Figure 3. The pilot lacks options that avoid convective weather and are not too far from the filed flight plan.

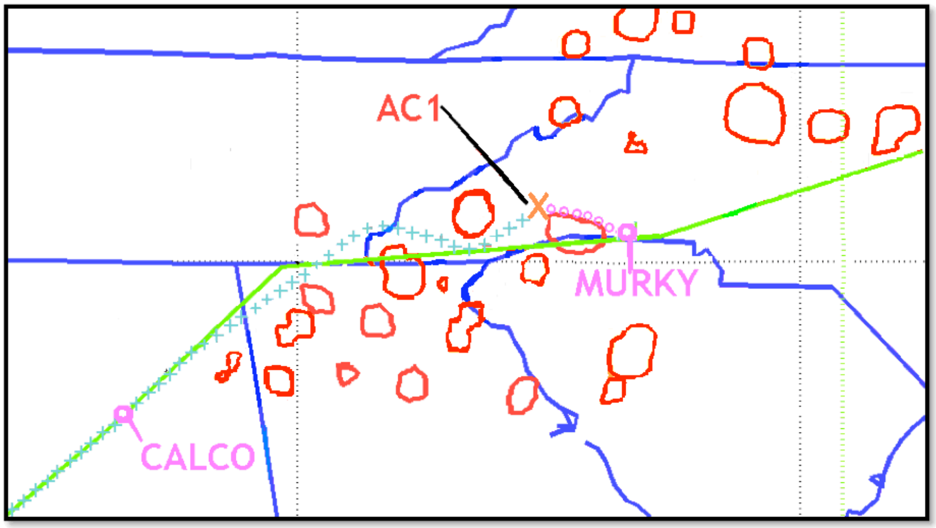

Figure 3. Deviation Clearance

Since the convective areas are scattered along the current route, the pilot would send a downlink message requesting a deviation due to weather for 40 nmi left or right of the flight plan. This deviation request will allow the pilot to choose where to fly and what regions of convective weather to fly through. The controller would see this request and respond with an Uplink Message (UM) granting the request to deviate.

AC1 – DM27 – REQUEST WEATHER DEVIATION UP TO [040] [L OR R]

ATC – UM82 – CLEARED TO DEVIATE UP TO [040] [L OR R] OF ROUTE

UM68 – REJOIN ROUTE BY [CALCO]

B. Heading

AC2 is flying east to New York in Figure 4. Several areas of convective weather lie along the current flight plan.

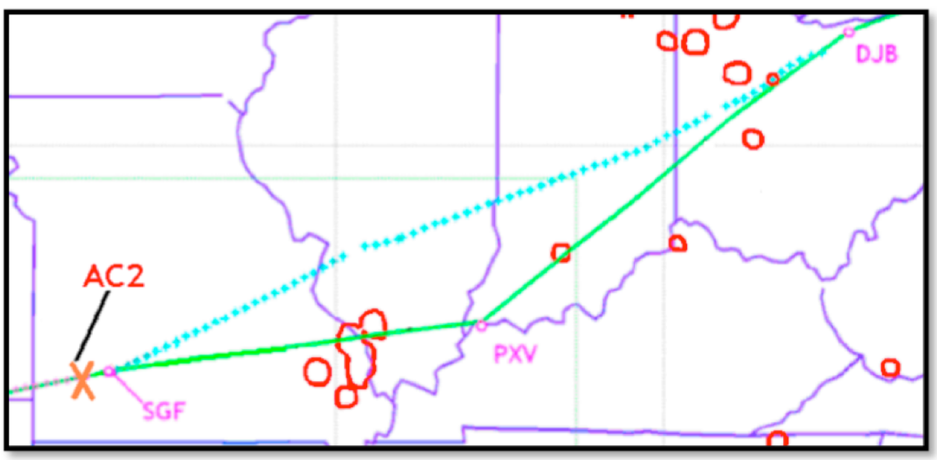

Figure 4. Heading Clearance

The pilot sees that there is an opportunity to avoid the convective weather ahead by requesting a heading direct to a waypoint downstream. The pilot could request a heading of 55˚ from magnetic north to avoid the convective weather and reduce travel time. The controller could issue the clearance by stating the point where the pilot may begin to fly the new heading. The controller must send UM68 telling the pilot where to rejoin the route.

AC2 – DM70 – REQUEST HEADING [055]

ATC – UM97 – AT [SGF] FLY HEADING [055]

UM68 – REJOIN ROUTE BY [DJB]

C. Offset

AC3 is flying west and has convective weather cells to the north and south of the filed route, shown in Figure 5.

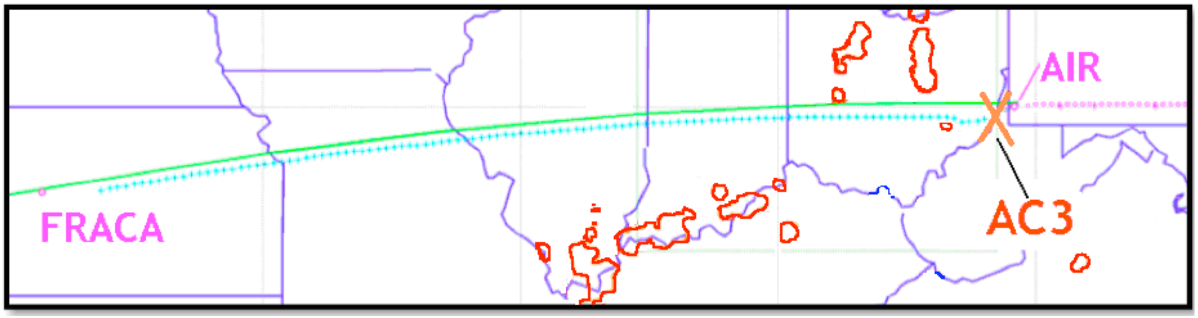

Figure 5. Offset Clearance

The pilot may initiate the clearance change by requesting an offset left of the route by 20 nmi to avoid the convective weather. The controller would respond with the point at which to begin the offset, the distance by which to offset, and whether to offset left or right of the route. Again, the controller must tell the pilot the point to rejoin the route.

AC3 – DM15 – REQUEST OFFSET [020] [L] OF ROUTE
DM65 – DUE TO WEATHER
ATC – UM65 – AT [AIR] OFFSET [020] [L] OF ROUTE
UM68 – REJOIN ROUTE BE [FRACA]

D. Route Clearance

AC4 is flying east on jet route 46. There is a large area of convective weather that might force the pilot to ask for a modified route, as shown in Figure 6. The pilot could send a request to avoid these areas.

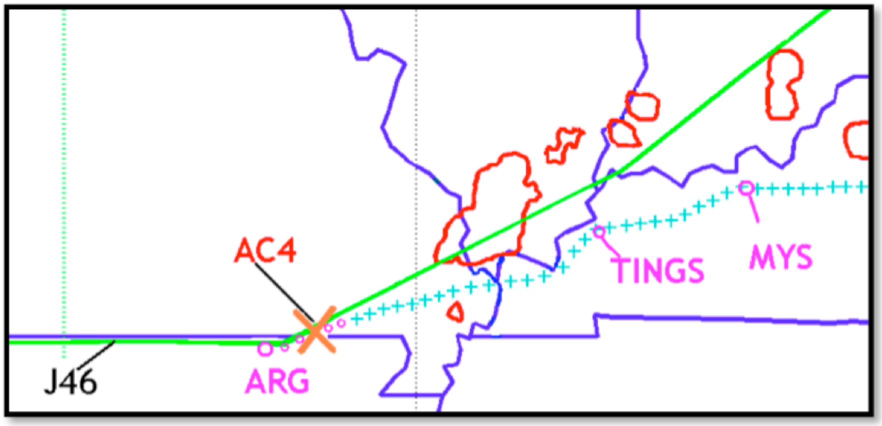

Figure 6. Clearance Requested by AC4

AC4 – DM25 – REQUEST CLEARANCE
DM65 – DUE TO WEATHER

The controller can see that the pilot wants to fly south of the convective weather, but the controller also sees that there is more convective weather ahead that the pilot might not see. Figure 7 displays the route clearance message that was issued. If AC4 is FANS 1/A-equipped, it is able to receive the route clearance from the ground that can be auto-loaded into the FMS.

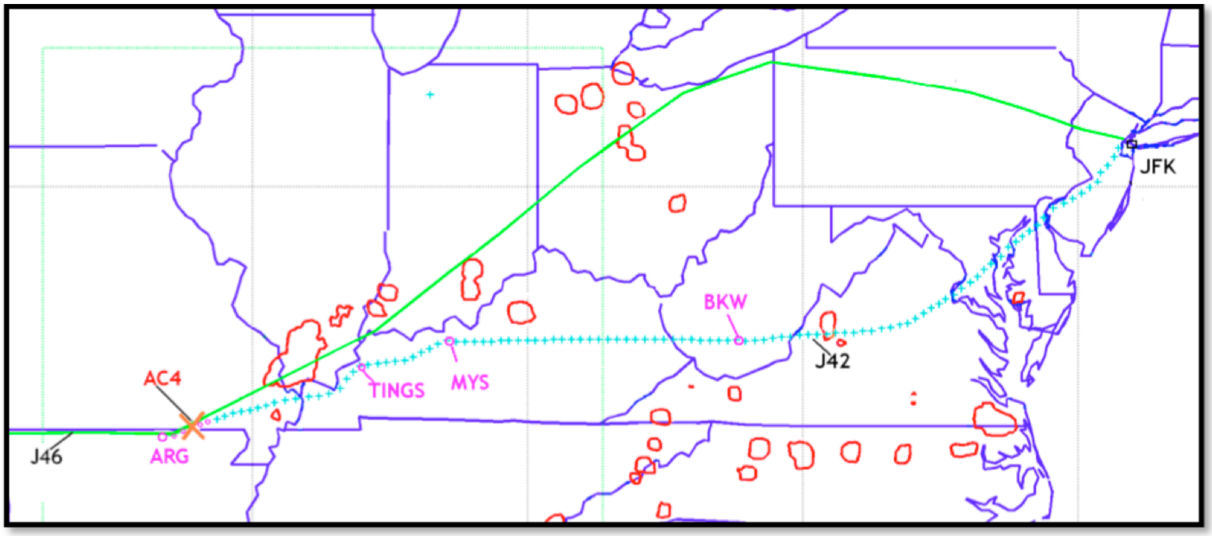

Figure 7. Route Clearance from Controller

ATC – UM79 – CLEARED TO [OTT] VIA [TINGS, MYS, BKW, J42]

V. Results

Analysis of the sort described above was conducted for 753 weather-impacted flights from the recorded data set. Figure 8 depicts the results. Fifty-two percent of weather-related trajectory changes could be accommodated with a deviation type of CPDLC message exchange. Some form of a heading message satisfied 25% of the clearances, and 17% could be described by a route clearance message. The remaining 6% were satisfied with an offset.

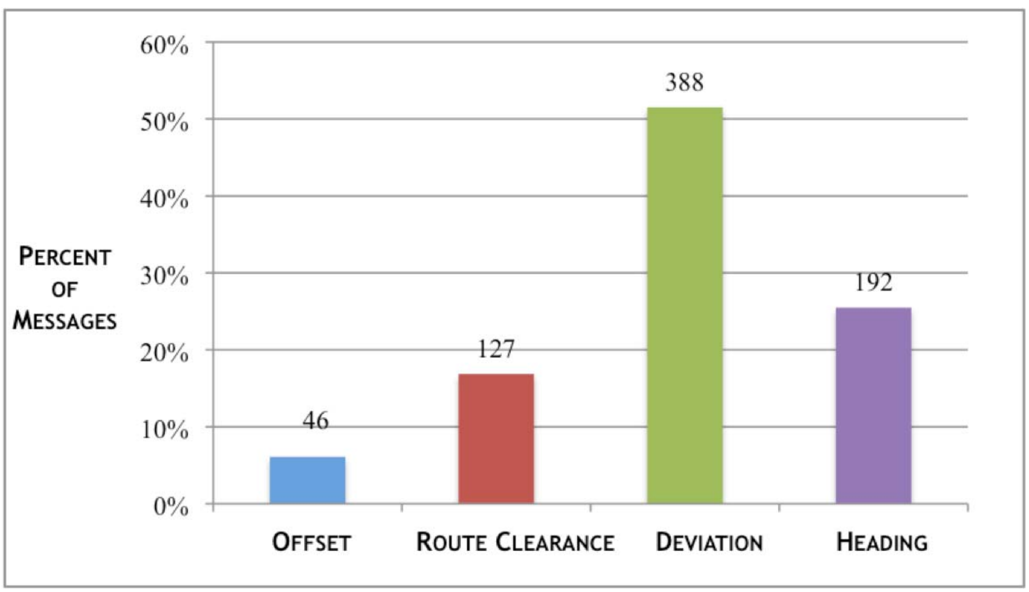

Figure 8. Datalink Messages for Weather Reroute

Deviations are advantageous because they give the flight crew flexibility in how they choose to maneuver through areas of convective weather. Headings allow for efficiency and are easily communicated over datalink communication. A route clearance permits efficient rerouting and can be very precise in details, but a route clearance can only be auto-loaded into the FMS of specially equipped (i.e., FANS 1/A) aircraft. For this particular data set, an offset was not as useful for weather avoidance. This may be dependent on the shape of the convective area and the geographical region that is studied.

VI. Summary

Eight hours of recorded traffic and convective weather were analyzed to determine the feasibility of using Controller-Pilot Data Link Communication to negotiate weather avoidance route amendments. 753 weather-impacted flights were identified by comparing each aircraft's filed flight plan to a probability contour map of airspace that flight crews were likely to avoid due to weather, as predicted by the Convective Weather Avoidance Model. Weather-avoidance maneuvers were mapped by hand to the appropriate datalink messages that would have been required to negotiate the associated clearance amendment. It was determined that all 753 clearance amendments could have been implemented using standard datalink messages and current-day procedures. A deviation message proved to be very applicable to weather avoidance and satisfied over 50% of the weather avoidance clearances. Heading and route-clearance maneuvers were satisfactory in accommodating another 42% of the weather re-routes. The remaining 6% were handled with an offset. These results indicate that it is indeed feasible to use CPDLC to negotiate weather avoidance route amendments, and, furthermore, relatively few CPDLC message types are required to meet the need. Both conclusions are relevant to designers of automation seeking to automate aspects of the weather re-routing task. Since the scope of this study was restricted to flights that encountered weather in the eastern half of the United States on one specific day, one next step would be to expand the scope to include other days and regions of the United States.

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