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ATM-WEATHER INTEGRATION AND TRANSLATION MODEL

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1. INTRODUCTION

A key Next Generation Air Traffic System (NextGen) Air Traffic Management (ATM)-Weather Integration concept is the process called *Weather Translation*. At a high level, this concept describes functionality which turns weather observations, analyses, and forecasts of meteorological parameters into operationally-meaningful, weather-related values such as threshold events or characterized National Airspace System (NAS) constraints.

Separate, downstream ATM functionality then takes the threshold events or characterized weather constraints and converts them into forecasts of NAS state changes or impact values, either of which can then be fed into ATM Decision Support Tools (DSTs) to assist in the development of appropriate ATM strategies. In this way, Air Navigation Service Providers (ANSPs) and the users of the NAS (Stakeholders) will be able to collaboratively plan, decide and execute ATM strategies based on a common understanding of weather constraints, rather than having to develop individual, sometimes conflicting interpretations of the underlying meteorological information.

The paper consists of the following sections:

- A high level definition of Weather Translation.
- Amplification of terms.
- Two examples of Weather Translation.
- A description of the ATM-Weather Integration Concept Diagram, which can be found in Appendix A.
- A brief summary of some key characteristics of Weather Translation.

These items provide additional detail and should assist in defining and scoping the functions that make up Weather Translation.

2. HIGH LEVEL DEFINITION OF WEATHER TRANSLATION

Weather Translation is comprised of one or more functions which ingest weather observations, analyses, and forecasts of meteorological parameters and automatically produce relevant, standardized *threshold events* or *characterizations of weather-related NAS constraints*. This is accomplished through a framework of aviation safety and operations filters such as Federal Aviation Regulations (FARs), flight standards, aircraft limitations and standard operating procedures (SOPs) and human factors filters such as pilot behaviors in the face of weather hazards. The results of Weather Translation may be in the form of *4-D* representations that are spatially and temporally relevant to the affected NAS element (e.g. airport, terminal area, region of en route airspace). This information can be utilized by ATM decision makers in assessing weather impacts on NAS operations.

3. AMPLIFICATION OF TERMS

With respect to Weather Translation, the term *threshold event* applies to a situation in which an atmospheric parameter such as cloud ceiling height, visibility or wind speed crosses a regulatory or operational threshold and may result in an associated change in the state of the affected NAS element, normally an airport. Examples of state changes for an airport include a runway configuration change, landing minima change, or arrival/departure rate change. A state change may or may not result in an increase or decrease in the capacity of the affected NAS element. For instance, an airport arrival rate change caused by the raising or lowering of a cloud ceiling implies either an increase or

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decrease in airport landing capacity, whereas a runway configuration change caused by a shift in wind direction does not necessarily result in any change in capacity.

In the context of this paper, weather-related NAS constraints are meteorological phenomena which are directly hazardous to aircraft. In the airport environment, these typically include hail and lightning, turbulence/winds/wind shear which exceed aircraft safety operating limitations and freezing and frozen precipitation occurring at rates which exceed aircraft operating capabilities. The same phenomena affect aircraft operations in the en route airspace, with freezing and frozen precipitation being replaced by icing which exceeds aircraft operating limitations. For reasons of safety, aircraft do not operate to, from or through NAS elements known to contain hazardous weather. Because aircraft avoid airports or airspace containing these hazards, the efficiency of the ATC procedures in, and overall capacity of, those airports and airspace are reduced.

A weather constraint can result in impact if the demand in the affected NAS element exceeds the capacity which has been reduced by that constraint. As used in the definition of Weather Translation, the term *characterization of weather-related NAS constraint* refers to the process of turning hazardous meteorological phenomena into values which reflect the degree to which the weather hazard would constrain the affected NAS element in the presence of air traffic. Although these characterizations are derived primarily from meteorological data, they are not expressed in traditional meteorological units of measure (e.g., feet, miles per hour, degrees). Rather, since they represent an amount of constraint, they are expressed in non-meteorological terms such as airspace permeability and displayed using representations such as avoidance fields. This information will be an input to downstream automated ATM processes that determine whether or not the weather constraint is likely to have an actual operational impact on the affected NAS element. The impact assessment is then provided to ATM decision support tools to facilitate planning and coordination with other affected NAS elements and to inform the collaborative decision making process.

Representations of weather-related NAS constraints which are derived from 4-D weather forecast products are likely to be presented as 4-D characterizations. The term *4-D characterization* refers to a gridded, volumetric framework of information in which each piece of information has four dimension (4-D) attributes: three spatial (location) dimension attributes (x, y and z representing, for example, latitude, longitude and altitude) and one temporal dimension attribute (t representing time). By inference, for any given 4-D forecast product or 4-D characterization, each grid location/time combination has an associated piece of information.

4. TWO EXAMPLES OF WEATHER TRANSLATION

The following sections contain brief scenarios which describe how weather translation might be used to identify a threshold event or a characterized weather-related NAS constraint. The scenarios also postulate how that information might be used by downstream functionality and systems to properly manage NAS resources through the threshold event or in the face of the characterized weather-related NAS constraint.

4.1 *Threshold Event*

The forecast from the NextGen 4-D Weather Data Cube suggests that a warm frontal passage and associated surface wind shift from 070 degrees (ENE) at 7 knots to 200 degrees (SSW) at 15 knots will take place in Atlanta at 1725Z. The Weather Translation functionality knows the superset of Atlanta runway configurations and the range of wind speeds and directions that should be used for each configuration. The predicted surface wind shift crosses from one of those ranges to another, implying that a threshold event is likely to take place which could result in a NAS state change (in this case, the airport switching from one runway configuration to another). The identification of this threshold event is the end product of the Weather Translation functionality, and it does not, in and of itself, drive a change to the runway configuration.

Once identified, the translated threshold event information is then fed directly into separate downstream ATM functionality that determines whether or not a state change is likely to take place, and the anticipated impact on NAS capacity (in this case, none) should it take place. ANSPs then utilize DSTs which have been informed by the state change information to determine an appropriate operating strategy. In this case, the DSTs calculate that, in order to most efficiently affect a change from an east runway configuration to a west runway configuration concurrent with the forecast wind shift at 1725Z, the Atlanta Terminal Radar Approach Control facility (TRACON) (A80) and the Atlanta Air Route Traffic Control Center (ARTCC) (ZTL) should begin reversing the arrival flows at 1711Z starting with flight

ABC123, and the Atlanta Air Traffic Control Tower (ATCT) should begin taxiing flights to the opposite end of the airport beginning with flight XYZ789, which has an estimated takeoff time of 1726Z. The affected ANSPs accept or modify the DST solutions as appropriate.

4.2 *Characterized Weather-Related NAS Constraint*

Based on objective *in-situ* turbulence reports from airborne aircraft and 4-D turbulence forecasts from the NextGen 4-D Weather Data Cube, Weather Translation functionality produces a 4-D characterization of the state of the airspace over a large portion of the Rocky Mountains. This representation depicts the expected permeability of the affected airspace by considering, among other things, the probability of occurrence and forecast intensity of the turbulence. The turbulence intensity is measured and stated in such a way as to allow for the determination of its expected impact on aircraft of different types, sizes, weights and altitudes. The 4-D characterization of the permeability of the airspace expressed by type and class of aircraft defines the limit of Weather Translation functionality.

This characterization can then be directly input into separate downstream ATM functionality that, based on the characteristics of the individual aircraft which are expected to traverse the affected airspace, determines the likely impact of the turbulence on that block of airspace, including identifying probable demand/capacity imbalances. These impact analyses are then provided to ANSPs and their decision support tools to assist in anticipating pilot requests for re-routes or developing mitigation plans for affected flows.

5. ATM-WEATHER INTEGRATION CONCEPT DIAGRAM DESCRIPTION

The Weather Integration Concept Diagram is located in Appendix A. It provides an overview of the envisioned NextGen weather concept for enhancing ATM decision making in the face of weather constraints. The diagram includes Weather Translation as one of its components.

The next four subsections of this portion of the paper contain descriptions of the major components contained in the figure. The final subsection is a general discussion of the concepts depicted in the diagram, including the interactions of the various components of ATM-Weather Integration. Attempts have been made throughout this portion of the paper to place Weather Translation in the proper context.

5.1 *Weather Information*

The graphics in the left-most portion of the diagram represent the observed, analyzed and forecast (predicted) meteorological parameters associated with the current or future state of the atmosphere. Where appropriate, forecasts are four dimensional (4-D) representations of the future state of the atmosphere. All of this weather information is managed by the NextGen 4-D Weather Data Cube and disseminated through the net-centric infrastructure.

5.2 *Weather Translation*

The yellow box in the left middle section of the diagram represents Weather Translation functionality. This functionality ingests weather observations, analyses and forecasts, most of which are likely to come from the NextGen 4-D Weather Data Cube. Through the framework of aviation safety and operations filters such as FARs, flight standards, aircraft limitations and SOPs and human factors filters such as pilot behaviors in the face of weather hazards, Weather Translation functionality automatically produces relevant, standardized threshold events and characterizations of potential weather-related NAS constraints. Where appropriate, the characterizations will be represented in 4-D.

5.3 *ATM Impact Conversion*

The red box in the right middle portion of the diagram represents ATM Impact Conversion functionality. This capability takes information from the Weather Translation function and converts it into potential NAS state changes (in the case of threshold events) or capacity impact (in the case of characterized weather-related constraints).

It does so by considering the effect of the forecast weather condition on the individual aircraft (demand) projected to be in the affected NAS element at the same time. Along with historical company operating practice filters, ATM Impact Conversion also does its calculations through the same framework of aviation safety, operations and human factors filters as does Weather Translation. Consequently, safety is taken fully into consideration by the functionality as it attempts to measure the effects of the threshold event or characterized weather constraint. The most accurate and up-to-date demand information is used prior to determining the magnitude of the impact.

In addition to weather constraints, this functionality can ingest non-meteorological constraint information such as Special Activity Airspace (SAA) and runway closure information and process it identically.

5.4 *ATM Decision Support*

The brown box on the far right side of the diagram represents the various ATM decision support tools and displays available to decision makers. These tools use the NAS impact analysis results from ATM Impact Conversion functionality in developing traffic management plans, strategic through tactical, that suggest the best operating strategies to deal with forecast changes of state of NAS components or that best mitigate the effects of the forecast set of constraints.

5.5 *General Discussion*

Weather Information (left-most side of the diagram) is the source of the observed, analyzed and forecast meteorological data for Weather Translation. Within the Weather Information area, the major source of the meteorological data for Weather Translation is planned to be the NextGen 4-D Weather Data Cube. However, it is possible that weather information that is not available through the NextGen 4-D Weather Data Cube may be used by Weather Translation functionality to identify threshold events and weather constraints of interest to ANSP and stakeholder personnel. This may be especially true during the transition period from today's non-integrated weather sources to tomorrow's full NextGen 4-D Weather Data Cube capability.

Some content may flow directly between Weather Information and direct FAA users or decision support tools without the need for Weather Translation or ATM Impact Conversion to be performed. For example, there is no value-added function required to modify or adjust upper level wind and t**e**mperature forecasts to support trajectory modeling. Therefore, it is not necessary for this information to go through Weather Translation or ATM Impact Conversion. It is assumed (and shown in the figure) that Weather Information will also be directly available to external NAS users.

Current plans are for Weather Information to be able to support trajectory- and volumetric-based retrievals of observations and forecasts by ANSPs from certain ATM Decision Support tools in support of, for example, flight service pilot briefing requests. External users will have similar access to Weather Information.

As illustrated by the icon in the upper left corner and the dashed vertical line down the middle of the figure, Weather Information and Weather Translation are the responsibility of the meteorological community. Primary responsibility for Weather Information rests with the National Weather Service (NWS), with Federal Aviation Administration (FAA) providing certain aviation-related observation and forecast support. The FAA meteorological community and the NextGen office responsible for weather-related advances, represented by the small blue box attached to the bottom of the yellow Weather Translation box, are primarily responsible for Weather Translation functionality.

Along with Weather Information, another key input to Weather Translation is represented by the light green figure directly above the yellow Weather Translation box called *ATM Aviation Standards*. This box consists of safety and regulatory items such as FARs, flight standards, aircraft limitations, federal SOPs and aviation specific hazard thresholds (e.g., turbulence vs. aircraft types). It may also reference predictors such as pilot/flight crew behaviors in the face of various types of weather constraints. The sum of these parameters defines the framework within which, and filters through which, weather translation functionality must operate. They are critical to the development of characterizations of potential weather constraints.

Weather Translation is a dynamic function. Depending on the type of subscription arrangement being used and based on pre-arranged criteria, the NextGen 4-D Weather Data Cube may push new meteorological data to Weather Translation whenever a parameter changes by more than some key amount (i.e., a significance threshold). In a similar fashion and based on agreed-upon standards, Weather Translation will then determine if the weather changes should trigger a revision to currently identified threshold events or characterized weather constraints. If it is determined that a revision is appropriate, the new threshold event information or characterized weather constraint may then be pushed to the appropriate ATM Impact Conversion functionality. It is thought that similar relationships and processes will exist between ATM Impact Conversion functionality and ATM Decision Support Tools.

One way to differentiate between Weather Translation and ATM Impact Conversion is by looking at their outputs. Those from Weather Translation functionality are threshold events and constraints based on every possible aircraft type, while ATM Impact Conversion functionality outputs an assessment of the impact of the weather constraint or threshold event on individual flights that make up anticipated flows.

Another way to describe the difference between Weather Translation and ATM Impact Conversion would be to note that the functions in the Weather Translation box do not know anything about the actual aircraft that are anticipated to use the NAS element during the time that the state change is forecast to occur or the constraint is forecast to be present. In contrast, the functions in the ATM Impact Conversion box are not only aware of the individual aircraft that are scheduled to use the NAS element during the affected time period, they use the information from the Weather Translation box to predict how those individual aircraft will behave in the face of the forecast weather constraint, or whether or not they will be able to continue to operate subsequent to the NAS state change. This, in turn, allows the ATM Impact Conversion functions to predict changes to the capacity of the affected element.

The development of Weather Translation functionality (yellow box) and ATM Impact Conversion functionality (red box) will undoubtedly require the simultaneous, cross-functional involvement of members of both the meteorological and ATM communities. For instance, the establishment of functional and performance requirements for Weather Translation will be driven by the needs of ATM Impact Conversion. This is why the lines of division between the adjacent areas are depicted using highly permeable dashed lines.

The icon in the upper right corner and the small blue box hanging from the red ATM Impact Conversion box are meant to indicate that responsibility for ATM Impact Conversion and ATM Decision Support functionality belongs primarily to the ATM community within the FAA and four of the NextGen offices responsible for the development of key ATM concepts. In addition to establishing the operational and performance requirements for the weather constraint information that will be provided by Weather Translation, these groups will have primary responsibility for the development of the ATM Impact Conversion functionality and the ATM decision support tools that utilize the impact information to assist ANSPs in ATM decision making and mitigation strategy development.

Along with the output of Weather Translation, there are two other key inputs to ATM Impact Conversion: *ATM Aviation Standards* (left-most light green box, as described previously) and *ATM Efficiency* (right-most light green box). The former provides the aviation filters through which the impacts of weather constraints on capacity will be calculated, while the latter input provides the basis for evaluating capacity alongside projected demand in order to determine if a problem (demand exceeding capacity) is likely to exist as a result of the weather constraint.

Although the primary users of ATM Impact Conversion output are the ANSPs and their decision support tools, it is assumed that Stakeholders and their decision support tools will also be able to gain access to the same information via a subscription service and/or on a request/reply basis. At a minimum, this information will assist stakeholders in understanding the basis upon which the FAA is making its decisions.

It is assumed that the NAS impact information from ATM Impact Conversion will be generally applicable to a wide range of ATM (ANSP and Stakeholder) decision support tools, which operate in all time horizons from tactical to long-term strategic. However, it is also assumed that this output will not necessarily be customized in such a way as to meet the content and format requirements of every single ATM DST. Some ATM Decision Support functionality may need to filter and/or reformat the content of the most appropriate ATM Impact Conversion output to meet its particular needs.

From an overall system perspective, it is helpful to think of information as flowing from left to right in this process, while requirements flow the opposite way, from right to left. This is depicted by the light yellow arrows located at the very top and very bottom of the diagram.

6. KEY CHARACTERISTICS OF WEATHER TRANSLATION

The following bullets summarize some of the key characteristics of Weather Translation:

- Weather Translation primarily supports ATM decision making by providing ANSP and stakeholder personnel a common view of potential weather constraints that may affect NAS operations, thereby alleviating the need for any individual interpretation of weather information and its predicted constraint.
- At maturity, it will use the NextGen 4-D Weather Data Cube as its primary source of weather observations, analyses, and forecasts.
- It develops a single source of 4-D characterizations of weather constrained NAS airspace within a geographical region of interest relevant to ATM decision makers.
- It will NOT actually perform operational impact assessments. Other downstream processes and functions (i.e., ATM Impact Conversion) will turn the constraint information into NAS capacity changes (e.g. limited capacity zones,

visibility impacts on airport operations) and then develop candidate mitigation strategies (i.e., ATM Decision Support and related DSTs).

- It is envisioned as being functionally and architecturally separate from the NextGen 4-D Weather Data Cube.
- Weather Translation will present the interpretation in terms of specific weather phenomena (e.g., convection, icing and turbulence), 3-D area of reference, applicable time period and probability of occurrence.
- Where appropriate and possible, the constraining phenomenon will be measured and stated in such a way as to allow for the determination of its expected impact on aircraft of different types, sizes, weights and altitudes.
- A quality-of-service description will be established for each Weather Translation product. This will enable applications which use Weather Translation products to select the most appropriate one(s) in terms of spatial and temporal resolution. For example, tactical terminal operations will require more precise resolution than an hours-in-advance TFM operation.
- Translated weather constraint information will be available to users both automatically (subscription) and via request/reply.

7. CONCLUSION

Weather Translation is a key enabling component of the ATM-Weather Integration concept. It promises to eliminate some of the shift-to-shift, day-to-day and facility-to-facility inconsistencies experienced today, as different ATM decision makers individually attempt to quantify the impact of a forecast weather constraint and then devise solutions based on their understanding. The ATM-Weather Integration Concept Diagram, whose first version was finalized less than a year ago, has been widely accepted. It has helped to solidify the notion of Weather Translation across a number of industry and government ATM decision making organizations.

However, Weather Translation is but one of four components of the ATM-Weather Integration concept. Members of the ATM and ATM research and development (R&D) communities, assisted by members of the weather R&D community as appropriate, must make meaningful progress in further defining the requirements associated with ATM Impact Conversion and ATM Decision Support systems. In addition, the ATM R&D community must identify, optimize and test the ATM Decision Support methodologies and tools best suited to utilize probabilistic, translated weather information. Only when all four of the components of the ATM-Weather Integration concept are comparably mature and effective will the benefits associated with the concept come to fruition.

8. DISCLAIMER

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Appendix A. ATM-Weather Integration Concept Diagram