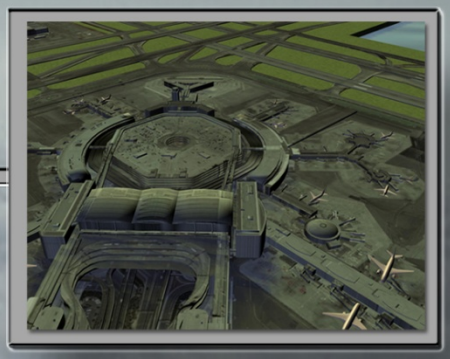
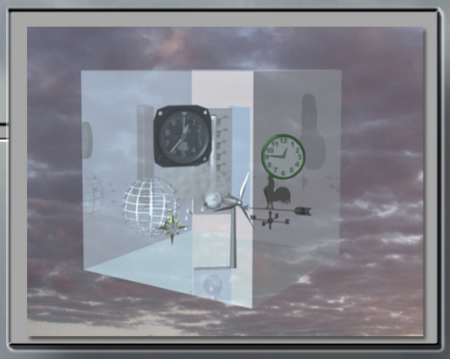
Joint Planning and Development Office

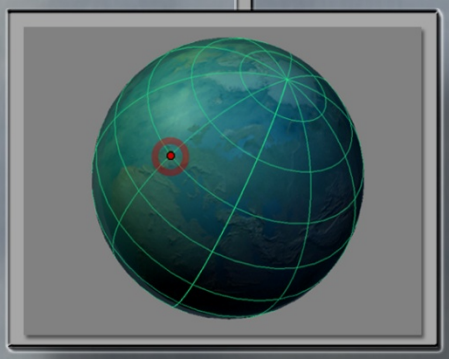
ATM-Weather Integration Plan

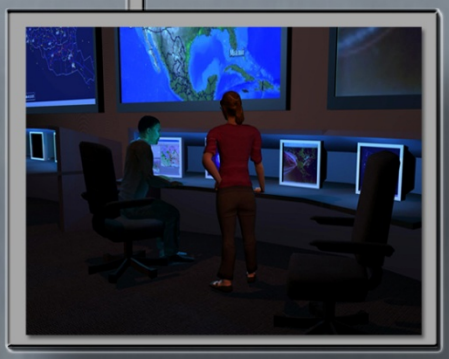
Version 0.8

July 10, 2009









Next Generation Air Transportation System
Joint Planning and Development Office

Joint Planning and Development Office (JPDO)

Next Generation Air Transportation System (NextGen)

ATM-Weather Integration Plan

DRAFT

Version 0.8

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DRAFT v0.8

ATM-Weather Integration Plan

EXECUTIVE SUMMARY

Weather accounts for 70%[1] of the $41B annually[2].cost of air traffic delays within the United States NAS, or $28B annually. Approximately two thirds ($19B) of these delays are considered to be avoidable.[3] The Weather – Air Traffic Management (ATM) Integration Working Group (WAIWG) of the National Airspace System (NAS) Operations Subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC) conducted a twelve-month study to examine the potential benefits of integrating weather and air traffic management. The report of this committee made several recommendations regarding integration of weather and the potential for weather integration to help reduce delays. The way to mitigate these delays and eliminate those that are avoidable is to improve the quality and method of use of weather information and evolve (integrate) the weather support to the NAS.

This NextGen Weather Integration Plan provides the initial requirements, scope, and implementation roadmap to achieve the NextGen vision; to enable decision makers to identify areas where and when aircraft can fly safely with weather assimilated into the decision making process in order to optimize the entire NAS. It also addresses agency roles and responsibilities and includes resource requirements. This plan establishes the approach to deal with the integration of weather information into the ATM decision making process.

Integration, as used in this plan, refers to the inclusion of weather information into the logic of a decision process or a decision aid such that weather impacts are taken into account when the decision is made or recommended. The goal of weather integration is to minimize the need for humans to gauge NAS weather impacts or to determine the optimum mitigation.

KEY POINT: Weather information is not presently integrated into all ATM decision systems and processes.

This plan addresses the following problem:

b) Most weather support to ATM is manual, with weather displays that must be interpreted by the user.

- Weather products do not have the maturity required for direct insertion without interpretation.*
- Rules for interpretation and use of weather data are generally based on the experience of the user.
- ATM decisions based upon today's weather products are inconsistent from user to user.

c) * This aspect of the problem is addressed in the NextGen Weather Plan

The figure below illustrates the process of moving from raw current and forecast weather data through the creation of weather products that relate weather data to aviation impacts and on to

[1] OPSNET
[2] Congressional Joint Economic Committee; May 2008
[3] REDAC Weather-ATM Integration Working Group Report; Oct 3, 2007

the generation of rules for decisions to be made by ATM operators and other users and ultimately to the creation of automated decision support tools.

KEY POINT: The process to flow from information on the state of the atmosphere to translation into impacts to decision rules on dealing with impacts to inclusion into decision systems.

State of the Atmosphere	Translated Impact Parameters	Decision Rules	Decision System
Examples: •Convective wx forecast •Turbulent eddy dissipation rate (EDR) From: weather systems Ownership: wx community with requirements from users Located: 4D Weather Data Cube	Examples: •CWAM •EDR index to aircraft type From: Appendix B Ownership: wx community with user guidance Located: multi-use in network service; unique in user systems	Examples: •Acceptable severity level •SFO parallel approach From: user community, with support from Appendix B Ownership: Users, with support from weather community Located: multi-use service; unique in user systems	Examples: •TFMS (Traffic Flow Management System) •TBFM (Time-Based Flow Management) From: users, and cataloged in Appendix A Ownership: users Located: user systems

At NextGen IOC (2013), some weather data will flow machine-to-machine with real integration into decision support tools (DST), but most integration of weather information will still be handled manually, with some data and displays provided to the cockpit for pilot decision. By the 2018 mid-term some DSTs will have integrated weather, and by 2025, weather information will be automatically translated to impact and ingested into most decision algorithms, both on the ground and in the cockpit.

KEY POINT: An analysis of weather impacts into decision tools has been done.

An analysis of the current state of weather integration was conducted and this plan lays out the weather integration opportunity in the NextGen solution sets; Initiate Trajectory Based Operations, Increase Arrivals/Departures at High density airports, Increase Flexibility in the Terminal Environment, Improve Collaborative ATM, Increase Safety, Security, and Environmental Performance, and Transform Facilities. Each solution set was broken down into

swim lanes, and then further into capabilities and associated Operational Improvements (OIs). This analysis is reflected in Section 3 of the Plan, along with the associated Appendix A.

KEY POINT: An analysis of available weather translation and decision methodologies has been done

ATM will require DSTs that can deal with the information from the 4-D Weather Data Cube (4D Wx Data Cube) which has been translated into NAS impacts and provide ATM with best choice options. The translation can be obtained by a network service for common use or by imbedding the translation capability in the DST for unique needs. Section 4 and the associated Appendix B provide a survey that identifies technologies and methodologies for translating weather information into ATM impacts in the NAS. The survey includes approaches for addressing weather-related uncertainty in ATM decision making – risk management processes. The survey is organized in two parts; ATM-Weather Impact Models and ATM-Weather Integration Techniques.

The Plan presents a summary of each of the surveyed ATM-impact models starting with models that were derived primarily for convection, and ending with a wide variety of models for several types of aviation hazards. This section assessed the maturity of the ATM-impact models presented, and identified gaps in technologies that must be addressed for NextGen.

KEY POINT: A foundation of mature, tested methodologies must be built and maintained, along with a capability for multi-use impacts translation.

Further research is required on the conversion of weather data into specific ATM impacts.

The execution of this plan will occur in four steps. The steps will be executed in sequential order from the start, but the steps will be repeated many times as new weather techniques and ATM tools are developed and may be occurring simultaneously at some point in the future. The steps are:

1. Align teams with each solution set and analyze weather integration requirements for a service and performance-based approach for weather integration as associated with operational relevance.
2. Identify the specific weather integration insertion points, including performance criteria and value, into ATM tool or decision platform functionality.
3. Identify and recommend the specific weather integration techniques and technologies that best fit the requirements of a particular traffic flow management tool under development and particularly the insertion points identified in the previous step.
4. Serve as the subject matter expert (SME) for the ATM tool development team to assist in integration of the weather methodologies and to evaluate test results.

KEY POINT: A DST-by-DST weather support activity must assist in successful weather integration.

The key interaction for success in weather integration will be the relationships established between the AWO and the ATM tool development community. The AWO role is to ensure

proper use and application of weather data and techniques in development of specific DSTs. During development, the AWO will fund demonstrations for specific technologies in order to demonstrate both the quality and usability of weather information in the decision process. It is imperative that human factors (see C-5) be considered in the development of every DST. As DST development proceeds, weather data for specific DSTs will transition from a testing scenario to inclusion of production data directly from the 4D Wx Data Cube.

Anticipated initial activities

FY10:

- Building weather translation and decision foundation, including test and evaluation capability.
- Stand up Weather Leadership Team and Integration Sub-Teams.
- Identify initial set of DSTs that have the potential for successful weather integration by NextGen IOC. Identify candidate methodologies, brief users, and develop demonstrations of weather methodologies that will yield success.

FY11:

- Conduct successful demonstrations of weather products or methodologies that have the necessary maturity level for integration

FY12:

- Work with user community and DST developers to integrate weather products and methodologies into DSTs for IOC implementation

TABLE OF CONTENTS

1 INTRODUCTION 1
1.1 Background 1
1.2 Purpose 1
1.2.1 Integration Definition 1
1.2.2 Integration Goal 1
1.3 Scope 2
1.3.1 Assumptions 2
1.3.2 Roles and Responsibilities 2
2 NEXTGEN WEATHER INTEGRATION OVERVIEW AND CONCEPT 4
2.1 Problem Statement 5
2.2 Weather Impacts on Solution Sets 8
2.3 Alternatives Considered for Integration 9
2.3.1 Status Quo – Do Nothing 9
2.3.2 Improve Weather Products to Enhance Usability by ATM 10
2.3.3 Integrate Weather Information into ATM Decision Support Tools 10
2.4 Recommended Solution: Integrate Weather into ATM Decision Support Tools 11
2.5 Anticipated Benefits and Impact 11
3 NEXTGEN WEATHER INTEGRATION: DECISION SUPPORT TOOLS 12
3.1 Trajectory Based Operations 15
3.2 High Density Airports 17
3.3 Flexible Airspace in the Terminal Area 19
3.3.1 Separation Management 19
3.3.2 Trajectory Management 20
3.3.3 Flight and State Data Management 21
3.4 Collaborative Air Traffic Management 22
3.4.1 Flight Contingency Management 22
3.4.2 Capacity Management 23
3.4.3 Flight and State Data Management 23
3.5 Increase Safety, Security and Environmental Performance (SSE) 25

3.6 Transform Facilities (Facilities) ... 25
3.7 Additional Initiatives and Targets: ... 25
4 TECHNOLOGY AND METHODOLOGY CONCEPTS ... 25
4.1 Survey of ATM-Weather Impact Models ... 26
4.2 Maturity and Gap Analysis ... 35
4.3 Survey of ATM-Weather Integration Technologies ... 38
4.4 Maturity and Gap Analysis ... 40
5 WEATHER INTEGRATION PLAN EXECUTION ... 42
5.1 Plan Execution ... 42
5.1.1 Foundation for Integration ... 42
5.1.2 Integration Process ... 43
5.2 Organization ... 46
5.2.1 Weather Leadership Team ... 46
5.2.2 Weather Integration Sub-Teams ... 47
5.2.3 Weather Integration Technology Evaluation Board ... 48
5.3 Cost, Benefits, and Schedule ... 48
5.4 Relationship of Integration with Aviation Weather Programs ... 49
6 ALIGNING THE WEATHER INTEGRATION PLAN WITH PREVIOUS FINDINGS AND RECOMMENDATIONS ... 50
6.1 Weather – ATM Integration Working Group (WAIWG) of the National Airspace System Operations Subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC) ... 51
6.2 NextGen Conference on Integrating Weather, Airports, and Air Navigation Services ... 51
6.3 Integration Teams Approach to Tracking the Status on the Previous Findings and Recommendations ... 52
6.4 Agency Approaches to Implementing the Findings and Recommendations ... 52
A. NEXTGEN WEATHER INTEGRATION: DECISION SUPPORT TOOLS, DECISION IMPLEMENTATION PLAN AND COST PROCESSES ... A-1
A-1. Initiate Trajectory Based Operations (TBO) ... A-1
A-1.1 Introduction ... A-1
A-1.2 Delegated Responsibility for Separation (OI-0355, NAS OI-102118) ... A-8
A-1.3 Oceanic In-trail Climb and Descent (NAS OI-102108) ... A-12

A-1.4 Automation Support for Mixed Environments (OI-0349, NAS OI-102137) A-14

A-1.5 Initial Conflict Resolution Advisories (NAS OI-102114)..... A-17

A-1.5.5 Mid-term Candidate Weather Integration..... A-19

A-1.6 Flexible Entry Times for Oceanic Tracks (OI-0304, NAS OI-104102)..... A-34

A-1.7 Point-in-Space Metering (NAS OI-104120)..... A-37

A-1.8 Flexible Airspace Management (OI-0351, NAS OI-108206) A-41

A-1.9 Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP) (OI-0311, NAS OI-108209) A-47

A-1.10 Findings, Conclusions, and Recommendations A-51

A-2. Increase Arrivals/Departures at High Density Airports A-53

A-2.1 Introduction..... A-53

A-2.2 Integrated Arrival/Departure Airspace Management (OI-0307, OI-104122)..... A-57

A-2.3 Time-Based Metering Using RNP and RNAV Route Assignments (OI-0325, OI-104123) A-69

A-2.4 Improve Operations to Closely Spaced Parallel Runways (OI-0333, OI-102141) A-77

A-2.5 Initial Surface Traffic Management (OI-0320, OI-104209)..... A-81

A-2.6 Findings, Conclusions, and Recommendations A-88

A-3. Increase Flexibility in the Terminal Environment..... A-89

A-3.1 Separation Management..... A-90

A-3.2 Trajectory Management A-96

A-3.3 Capacity Management A-99

A-3.4 Flight and State Data Management..... A-100

A-4. Improved Collaborative Air Traffic Management (CATM) A-107

A-4.1 Flight Contingency Management..... A-107

A-4.2 Capacity Management A-118

A-4.3 Flight and State Data Management..... A-119

A-4.4 Additional Initiatives and Targets..... A-136

B. TECHNOLOGY AND METHODOLOGY B-1

B-1. Survey of ATM Weather Impact Models B-1

B-1.1 En route Convective Weather Avoidance Modeling B-1

B-1.2 Terminal Convective Weather Avoidance Modeling B-2

B-1.3 Mincut Algorithms to determine Maximum Capacity for an Airspace B-3

B-1.4 Weather-Impacted Sector Capacity considering CWAM and Flow Structure B-4

B-1.5 Route Availability in Convective Weather B-6

B-1.6 Directional Capacity and Directional Demand B-7

B-1.7 ATM Impact based on the Weather Impacted Traffic Index B-9

B-1.8 Weather-Weighted Periodic Auto Regressive Models for Sector Demand Prediction B-10

B-1.9 ATM Impact in terms of a Stochastic Congestion Grid B-11

B-1.10 Translation of Ensemble Weather Forecasts into Probabilistic ATM Impacts B-12

B-1.11 Translation of a Deterministic Weather Forecast into Probabilistic ATM Impacts B-13

B-1.12 Sensitivity of NAS-wide ATM Performance to Weather Forecasting Uncertainty B-15

B-1.13 Use of Probabilistic Convective Weather Forecasts to Assess Pilot Deviation Probability B-17

B-1.14 Integrated Forecast Quality Assessment with ATM Impacts for Aviation Operational Applications B-18

B-1.15 Conditioning ATM Impact Models into User-relevant Metrics..... B-19

B-1.16 Integration of the Probabilistic Fog Burn Off Forecast into TFM Decision Making B-20

B-1.17 Mincut Algorithms given Hard/Soft Constraints to determine Maximum Capacity B-22

B-1.18 ATM Impact of Turbulence B-23

B-1.19 Tactical Feedback of Automated Turbulence electronic Pilot Reports..... B-25

B-1.20 ATM Impact of Winter Weather at Airports..... B-26

B-1.21 ATM Impact of In-Flight Icing B-26

B-1.22 ATM Impacts Derived From Probabilistic Forecasts for Ceiling and Visibility and Obstructions to Visibility B-27

B-1.23 Improved Wind Forecasts to predict Runway Configuration Changes..... B-28

B-1.24 Improved Wind Forecasts to facilitate Wake Vortex Decision Support..... B-30

B-1.25 Impact of Winds Aloft on the Compression of Terminal Area Traffic Flows B-32

B-1.26 Oceanic/Remote Weather Integration B-32

B-1.27 Translation of Volcanic Ash Plume Hazards onto Airspace and Airport Impacts B-33

B-1.28 Translation of Atmospheric Effects into Environmental and ATM Impacts .. B-34

B-1.29 ATM Impact of Space Weather B-35

B-1.30 ATM Impact of Weather Constraints on General Aviation Access to the NAS. B-36

B-2. Methodologies for ATM Weather Integration..... B-38

B-2.1 Sequential, Probabilistic Congestion Management for addressing Weather Impacts B-38

B-2.2 Sequential Traffic Flow Optimization with Tactical Flight Control Heuristics . B-40

B-2.3 Airspace Flow Programs to address 4D Probabilistic Weather Constraints..... B-41

B-2.4 Ground Delay Program Planning under Capacity Uncertainty..... B-42

B-2.5 Contingency Planning with Ensemble Weather Forecasts and Probabalistic Decision Trees B-44

B-2.6 Probabilistic Traffic Flow Management B-46

B-2.7 A Heuristic Search for Resolution Actions in Response to Weather Impacts.... B-48

B-2.8 Integrated Departure Route Planning with Weather Constraints..... B-50

B-2.9 Tactical Flow-based Rerouting B-51

B-2.10 Tactical On-Demand Coded Departure Routes (CDRs) B-52

B-3. References B-53

C. INTEGRATION PROGRAM PLAN C-1

C-1. Weather Integration Budget..... C-1

C-2. Weather Integration Benefits..... C-1

C-3. Schedule..... C-1

C-4. Risk Assessment C-6

C-5. Human Factors Considerations..... C-6

C-6. Training C-6

C-7. Intellectual Property Rights Considerations C-6

D. INTEGRATION PLAN TRACEABILITY WITH PREVIOUS STUDY GROUPS..... D-1

D-1. REDAC Recommendations and Response..... D-1

D-2. Integration Plan Alignment with Weather ATM Integration Conference Recommendations..... D-16

E. CURRENT ATM TOOLS E-1
F. ACRONYMS F-1

LIST OF FIGURES

Figure 2-1 Conceptual Flow 5

Figure B-14 Convective forecast transformed into ATM impact in various formats..... 26

Figure B-1 CWAM implementation to create WAFs. B-1

Figure B-2 Arriving pilots penetrate weather that departures seek to avoid..... B-3

Figure B-3 The translation of convective weather into maximum ATM throughput. B-4

Figure B-4 Weather impacted sector capacity estimation..... B-5

Figure B-5 Maxflow/Mincut and Route Blockage estimate route availability in structured, en route airspace (left) and flexible routing to avoid terminal area convective weather (right). B-7

Figure B-6 Directional capacity and demand rose chart. B-8

Figure B-7 Factors included in a WITI calculation..... B-10

Figure B-8 Stochastic congestion grid with combined traffic and weather constraint probabilities. B-12

Figure B-9 Procedure for translating an ensemble of weather forecasts into a probabilistic capacity map in terms of likelihood of a given capacity reduction. B-13

Figure B-10 Weather forecast errors characterized in terms of coverage, timing, and translational errors create an ensemble of weather constraints for a probabilistic ATM-impact assessment. B-15

Figure B-11 NAS performance sensitivities of trajectory-based and flow-based operations performance improvements and agile versus non agile decision making..... B-17

Figure B-12 Transforming a probabilistic NCWF-6 forecast into probability of penetration. B-18

Figure B-13 Sector-based verification of a 2-hour forecast and observations (impacted sectors are color-coded to depict the verification results)..... B-19

Figure B-14 Convective forecast transformed into ATM impact in various formats..... B-20

Figure B-15 Convective forecasts for use by automated ATM planners (impacted sectors are red for high impact and blue no impact)..... B-20

Figure B-16 Integration of a Probabilistic Forecast of Stratus Clearing with TFM..... B-21

Figure B-17 Capacity computation for two classes of aircraft among hard and soft constraints. B-23

Figure B-18 Causality diagram for turbulence. B-24

Figure B-19 Feedback of e-PIREP CIT turbulence data transformed into hazard regions. B-26

Figure B-20 In-flight icing causes significant ATM impacts..... B-27

Figure B-21 Causality Diagram for Terminal C&V. B-29

Figure B-22 Conceptual timeline showing traffic flow management in response to reduced wake vortex separations for arrival aircraft. B-31

Figure B-23 Causality diagram ATM impacts of volcanic ash. B-34

Figure B-24 The sequential, probabilistic congestion management concept as a control loop... ..... B-39

Figure B-25 Sequential optimization with strategic and tactical weather translation. B-40

Figure B-26 In an AFP, routes within the FCA are defined by an FCA planning DST to maximize throughput given weather constraints; routes outside the FCA are determined by routing preferences of the user. B-42

Figure B-27 A dynamic stochastic algorithm for planning and controlling a GDP. B-44

Figure B-28 Probabilistic decision tree reasoning with an ensemble of weather forecasts. B-46

Figure B-29 Example histogram of flight congestion costs. B-47

Figure B-30 Congestion management algorithm flow diagram. B-49

Figure B-31 Integrated Departure Route Planning Concept. B-51

Figure B-32 Example flow reroute. B-51

Figure B-33 On-Demand CDRs between pitch and catch gates from Airport A to B. B-53

LIST OF TABLES

Table 2-1 Alternatives Considered for Providing Weather Information 9

Table 4-1. Level of Maturity for ATM-impact Models. 35

Table 4-2. Level of Maturity for ATM-Weather Integration Technologies 40

Table A-1.2.6 Delegated Responsibility for Separation – Linkage to Near- and Far-term A-9

Table A-1.2.8 *Delegated Responsibility for Separation* – Mid-term Weather Needs AnalysisA-12

Table A-1.3.6 *Oceanic In-trail Climb and Descent* – Linkage to Near- and Far-term..... A-13

Table A-1.3.8 *Oceanic In-trail Climb and Descent* – Mid-term Weather Needs Analysis..... A-14

Table A-1.4.6 *Automation Support for Mixed Environments* – Linkage to Near- and Far-term A-16

Table A-1.4.8 *Automation Support for Mixed Environments* – Mid-term Weather Needs Analysis A-17

Table A-1.5.6 *Initial Conflict Resolution Advisories* – Linkage to Near- and Far-term A-20

Table A-1.5.8 *Initial Conflict Resolution Advisories* – Mid-term Weather Needs Analysis.... A-31

Table A-1.6.6 *Flexible Entry Times for Oceanic Tracks* – Linkage to Near- and Far-term... A-35

Table A-1.6.8 *Flexible Entry Times for Oceanic Tracks* – Mid-term Weather Needs Analysis.. A-36

Table A-1.7.6 *Point-in-Space Metering* – Linkage to Near- and Far-term A-39

Table A-1.7.8 *Point-in-Space Metering* – Mid-term Weather Needs Analysis..... A-40

Table A-1.8.6 *Flexible Airspace Management* – Linkage to Near- and Far-term..... A-43

Table A-1.8.8 *Flexible Airspace Management* – Mid-term Weather Needs Analysis A-46

Table A-1.9.6 *Increase Capacity and Efficiency Using RNAV and RNP* – Linkage to Near- and Far-term..... A-49

Table A-1.9.8 *Increase Capacity and Efficiency Using RNAV and RNP* – Mid-term Weather Needs Analysis..... A-51

Table A-2.2.6 Integrated Arrival/Departure Airspace Management – Linkage to Near- and Far-term A-62

Table A-2.2.8 Integrated Arrival/Departure Airspace Management – Mid-term Weather Needs Analysis..... A-66

Table A-2.3.6 Time-Based Metering Using RNP and RNAV Route Assignments – Linkage to Near- and Far-term..... A-72

Table A-2.3.8 Time-Based Metering Using RNP and RNAV Route Assignments – Mid-term Weather Needs Analysis A-73

Table A-2.4.6 Improve Operations to Closely Spaced Parallel Runways – Linkage to Near- and Far-term A-79

Table A-2.4.8 Improve Operations to Closely Spaced Parallel Runways – Mid-term Weather Needs Analysis..... A-81

Table A-2.5.6 *Initial Surface Traffic Management* – Linkage to Near- and Far-term A-84

Table A-2.5.8 *Initial Surface Traffic Management* – Mid-term Weather Needs Analysis..... A-86

Table A-5 CATM Concept Engineering Initiatives..... A-109

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DRAFT v0.8

ATM-Weather Integration Plan

1 INTRODUCTION

There is a need for a multi-agency, synchronized plan to achieve solutions to the problem of weather integration into ATM operations and decisions. As articulated in the NextGen vision, the solution must enable decision makers to identify areas where and when aircraft can fly safely with weather assimilated into the decision making process in order to optimize the entire national airspace system. The NextGen Weather Integration Plan provides the initial requirements, scope and implementation roadmap to achieve the NextGen vision. It also addresses agency roles and responsibilities and includes resource requirements.

1.1 Background

Weather accounts for 70 percent of all air traffic delays within the United States National Airspace System (NAS). The total cost of these delays has been estimated to be as much as $41B annually with weather delays costing over $28B annually. Approximately two thirds of weather delays have been estimated to be avoidable. The way to mitigate weather delays and eliminate avoidable delays is to improve the quality of weather information and to evolve weather support to the NAS both in quality and in methods of use, from its current levels to new targeted approaches.

1.2 Purpose

This plan establishes the approach to deal with the integration of weather information into the ATM decision making process.

1.2.1 Integration Definition

Integration as used in this plan refers to the inclusion of weather information into the logic of a decision process or a decision aid such that weather impacts are taken into account when the decision is made or recommended. This applies whether the decision is made individually or jointly by air navigation service providers and airspace users.

1.2.2 Integration Goal

The goal of weather integration is to minimize the need for humans to gauge NAS weather impacts or to determine the optimum mitigation. Today, weather integration is nearly all manual by decision makers after they view stand-alone weather products. Weather integration in NextGen will be an evolving process:

- At NextGen IOC (2013)
  - Some weather data will flow machine-to-machine with real integration into decision support tools (DST).
  - Most integration of weather information will still be handled manually but with improved “high glance value” products.
  - Some new data and displays will be provided to the cockpit for pilot decisions.

- By the 2018 mid-term some DSTs will have integrated weather.
- By 2025, weather information will be automatically translated to impacts and ingested into most decision algorithms both on the ground and in the cockpit.

1.3 Scope

This Plan addresses actions to be taken by the weather community, generally under weather community funding. Although it calls for close interaction with various user programs, it does not commit those programs or their managers to take any action or expend any funds. However, to benefit from the efforts described in the Plan, it is understood that the user programs must cooperate and participate in the process.

The cost of implementing the methodologies developed under and presented in the Plan will be born by the user programs. For example, where weather integration is to occur in some NAS system, the manager of that system must write the software code which implements the methodology. The weather community will support this by providing any reusable code to which it has access.

In the event that any user tool or capability must be cancelled or postponed, its description in this Plan does not in any way obligate the program manager to continue the program.

The Plan is intended to addresses weather integration into ATM decisions made by the ANSP or by the ANSP in collaboration with the AOC/FOC or operators. AOC/FOC and flight deck decisions unique to the operator (i.e. excluding ANSP participation) are not a subject for intervention in the Plan. Those are principally left for market innovation to develop and implement.

1.3.1 Assumptions

The creation and production of appropriate weather analyses and forecasts is to be addressed elsewhere and is outside of the scope of the integration effort. However, the Integration effort will address the identification of user requirements for weather information which will be conveyed to the developers.

The regulatory approval process for the use of new weather analyses and forecasts is to be addressed elsewhere and is outside of the scope of the integration effort. However, the Integration effort will support the regulatory process by providing rationale and other supporting documentation on how the information is to be used.

The SOA/IT infrastructure associated with publication of weather analyses and forecasts is to be addressed elsewhere and is outside of the scope of the integration effort. However, the Integration effort will act as an intermediary between the weather IT community and the user system owners to ensure that appropriate weather-related information flow occurs.

1.3.2 Roles and Responsibilities

Agency and community roles are as follows.

1.3.2.1 FAA

The FAA will be the primary actor to the extent that most ATM systems are owned by the FAA and the ATM-Weather Integration Process resides primarily within the FAA. However, for success, other agencies and stakeholders must be involved.

1.3.2.2 NASA

NASA will continue to be a major developer of ATM tools and techniques, and also of weather integration methodologies. NASA will share the fruits of its development with the other stakeholders for implementation and deployment.

1.3.2.3 DOD

The DOD has developed and is expected to continue to develop tools and methodologies which have application to the civil aviation community, including some relevant to weather integration efforts. To the extent possible, the DOD will share its developments with the broader NextGen weather integration community.

DOD will also cooperate in the development of weather integration capabilities

- When civil aircraft operate in military-controlled airspace.
- When civil aircraft operate at military airfields or joint-use fields operated by the DOD.
- When the weather integration community considers the hand-off point/procedures of aircraft between civil and military control.

1.3.2.4 NOAA

NOAA is the principal provider of weather information in the NextGen 4D Wx Data Cube, and that is the primary NOAA weather role, rather than integration into ATM decisions. For more information on NOAA and the 4D Wx Data Cube, see the NEXTGEN Weather Plan, which is a companion document to this Integration Plan.

1.3.2.5 Private Sector

This Plan does not in itself obligate the Private Sector to take any action. However, when weather-integrated ATM capabilities become operational, Private Sector users will be affected. To the maximum extent possible, writers and executors of this Plan will take the needs of the Private Sector into account, such as by refraining from unnecessary equipage requirements. Through the NextGen Institute, members of the Private Sector have participated in the preparation of the Plan and will be encouraged to continue their participation. The Government will make every effort to involve the Private Sector and keep the Private Sector informed of any decision which may affect the Private Sector.

1.3.2.6 International

Both weather and aviation are International enterprises. As with other NextGen developments, the weather Integration community will seek to harmonize itself with related International efforts, such as those in Single European Sky ATM Research (SESAR), the International Civil Aviation Organization (ICAO), and the World Meteorological Organization (WMO).

2 NEXTGEN WEATHER INTEGRATION OVERVIEW AND CONCEPT

Weather integration pertains to the inclusion of weather information into the logic of a decision process or decision aid such that weather impacts have already been taken into account when the decision (e.g. any decision affecting TFM) is made or recommended. Weather integration into NAS decisions is fundamentally the responsibility of the user community (i.e., ATC service providers and NAS operators), with the weather community in a supporting role. The ultimate goal of integration is to translate weather information as purely meteorological data into weather impacts on air traffic operations – essentially making weather transparent to its end users. The JPDO 4D Weather Functional Requirements for ATM calls for "weather integrated directly into sophisticated decision support capabilities to assist decision makers." Under the solution set of Reduce Weather Impacts within FAA's OEP program is a goal of making weather information seamless to users by integrating it into decision-making automation. As more meteorological parameters are fully integrated into DSTs, the need for direct M2M ingestion of weather data will increase. At the same time, the numbers of human-readable graphical displays and text messages may be allowed to decrease as appropriate. The previous notwithstanding, it is clear that operational decision makers on the ground and in the air will require both the graphical and textual representation of meteorological information for the foreseeable future.

Decision support will evolve over the next decade and beyond. Today, most weather-related decisions are made by ATM in a completely manual mode. With few exceptions, weather data are displayed as graphics or text at the Command Center, at TRACONs, ARTCCs, AOC/FOCs, Flight Services, and in cockpits all on stand-alone systems. By NextGen IOC in 2013 some weather data flow will be via M2M means. Most integration will remain in a manual mode but many weather displays will be improved to a "high glance value" mode. Data and displays will also be provided to the cockpit for pilot decision via electronic flight bags and existing on-board systems on some aircraft. By 2025 it is expected that weather information will be automatically translated into probabilistic weather impacts on air traffic and be ingested into decision algorithms (ground and aircraft).

Figure 2-1 first shows the process of moving from weather data which describes the state of the atmosphere at a current or future time through conversion of that data into weather impact parameters. As shown in the figure, the creation of the state of the atmosphere and then specific products which translate the raw weather information into impacts on aviation are the responsibility of the weather community in response to guidance from the user community. The user community then generates the rules for decisions that rely on weather data and impacts and then develops automated decision support tools which meet their specific operational needs. Once the process flow moves from weather impacts to development of decision rules, the

weather community has the responsibility for support and advice to the user community related to the use and interpretation of the weather data or derived weather product.

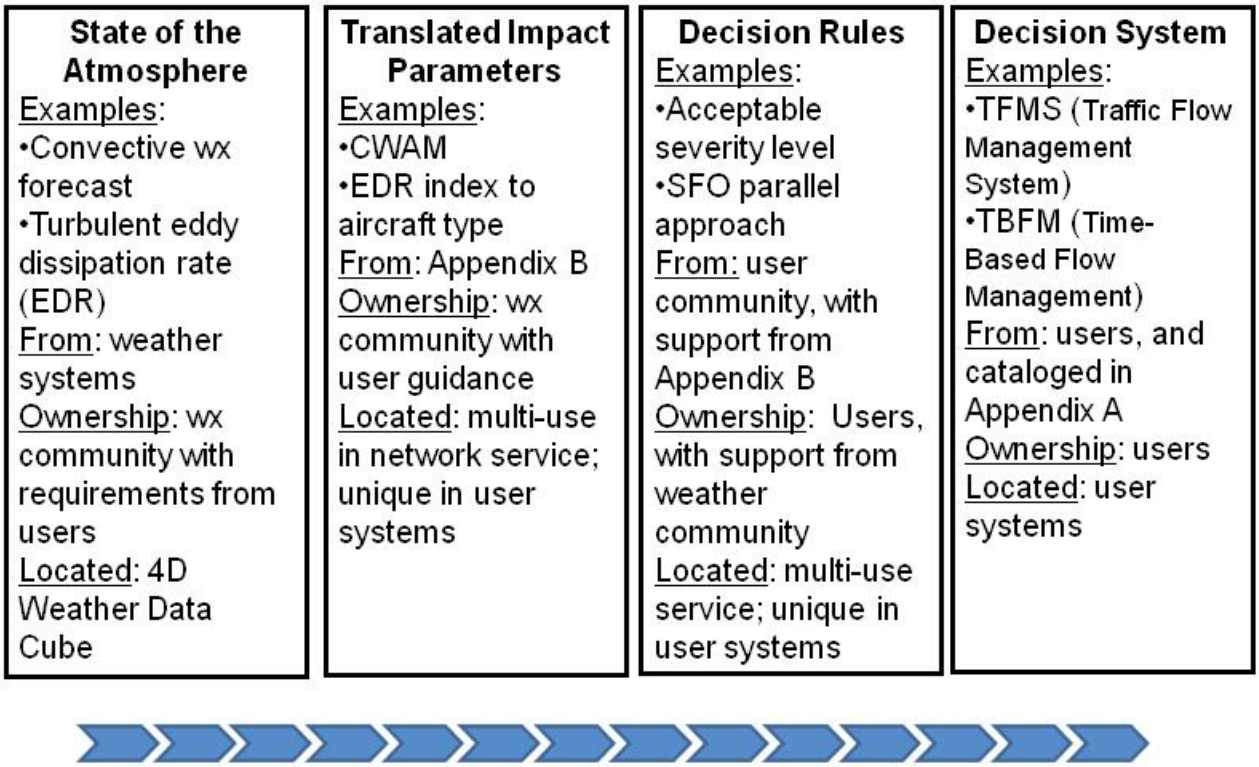


Figure 2-1 Conceptual Flow

2.1 Problem Statement

Problem Summary:

d) Most weather support to ATM is manual, with weather displays that must be interpreted by the user.

- Weather products do not have the maturity required for direct insertion without interpretation.*
- Rules for interpretation and use of weather data are generally based on the experience of the user.
- ATM decisions based upon today's weather products are inconsistent from user to user.

e) * This aspect of the problem is addressed in the NextGen Weather Plan

Discussion of the problem:

Today's national air transportation system is susceptible to weather disruptions causing flight delays, the impacts of which can be wide spread. Fast moving summer or winter storms impacting one hub airport or key transcontinental route can ground aircraft thousands of miles away, further propagating flight delays and cancellations. Weather delays are more than an inconvenience; they cost the nation's airlines, cargo carriers, corporate, and private users in excess of $28 billion annually. While severe weather will likely continue to prevent airspace and airport access in the immediate vicinity of the event, many delays could be avoided with better ways of dealing with weather throughout the national air transportation system.

Current weather products are not at a maturity level which allows direct machine-to-machine, automated use of weather data; rather, weather products today generally require human evaluation and interpretation. The skill in some key weather forecast products is inconsistent day-to-day and as a result, rules for making use of weather products in decisions are human derived, leading to inconsistent decisions by the user community. Many weather products or tools are "bolt on" systems that must be interpreted by the user and figured into traffic decisions based the user's understanding of the information presented. The weather data provided by these systems may not be provided in a manner that is useful in human made traffic flow decisions. Automated systems, many of which are designed around fair weather scenarios, must be shut down when significant weather impacts operations. Lack of automated tools necessitates a cognitive, reactive, inefficient weather-related decision making process and a meteorological competency of decision makers. The weather information used for this manual process is gathered from multiple sources. Individual controller perceptions are used to determine which is the "best source".

Where processes disregard weather data, many times this can be traced to the fact that the present weather data system is a collection of diverse, uncoordinated observations, forecasts and supporting systems. This does not support the need for "information rather than data" where information implies an underlying process and system to help make an informed decision. Indeed, today's weather system infrastructure to support timely and collaborative air transportation decisions necessary to effectively deal with bad weather does not exist.

DSTs are generally software applications used to automate the weather impact evaluation and air traffic/customer response. Mission Data are input into the DST, typically in the form of a proposed 4-dimensional trajectory through space and time. Along with trajectory information are added the particular weather sensitivities or risk tolerance of the flight under consideration. According to the spatial and temporal attributes of the mission (takeoff time/place, flight level, waypoints, and estimated landing time/place) relevant weather information is retrieved by subscription or by query/response from the 4-D Weather Data Cube (4-D Wx Data Cube) using XML standard queries. The DST then automatically compares the weather parameters to particular sensitivities of the mission under consideration. By applying relevant rules and thresholds (e.g. pilot landing minima, aircraft weather avoidance limits, risk tolerance, Federal Aviation Regulations, etc.) the DST converts weather information into weather impacts. The result of this logical integration is an output decision aid. For instance, the latter segments of a proposed trajectory may enter an area of forecast turbulence. If this forecast turbulence exceeds certain severity or probability limits the DST automatically flags these segments as, for example;

Red. More sophisticated DSTs may recommend weather-optimized trajectories through an iterative process of query and response. Thus, the trajectory flagged as Red for turbulence initially may be rendered Green by an earlier takeoff, a higher flight level, or a different route.

DSTs will take a number of forms and functions as NextGen evolves. There are 4 levels of integration each with increasing levels of complexity (note: The following does not consider where or how any DST will be displayed or used. Individual DSTs may require human factors (see C-5) consideration):

- Level 1: Stand-alone (little to no weather integration)
- Level 2: High "glance value" weather impact products
  - Operations-oriented weather impact data provided to the operator such as "stop light" displays, color coded views of aircraft trajectories according to weather impact
  - These displays allow the operator to mentally factor weather into decisions
- Level 3: User-in-the-loop tools
  - These tools have a M2M interface with algorithms suggesting solutions to the user for acceptance, rejection, or modification
  - Data for these tools will come from the 4-D4-D Wx Data Cube with associated confidence values
- Level 4: Fully integrated tools
  - These will be automated DSTs with full M2M data interface
  - Data will come from the 4-D4-D Wx Data Cube generally in probabilistic form with confidence values
  - No interpretation of weather will be required by the operator but the operator will be able to drill down into the decision if desired.

ATM will require DSTs that can deal with the information from the 4-D Wx Data Cube which has been translated into NAS traffic impact values impacts and provide ATM with best choice options. The translation can be obtained by a network service for common use or by imbedding the translation capability in the DST for unique needs. Section 4 and the associated Appendix B provide a survey that identifies technologies and methodologies for translating weather information into ATM impacts in the NAS. The survey includes approaches for addressing weather-related uncertainty in ATM decision making – risk management processes. The survey is organized in two parts; ATM-Weather Impact Models and ATM-Weather Integration Techniques. The Plan presents a summary of each of the surveyed ATM-impact models starting with models that were derived primarily for convection, and ending with a wide variety of models for several types of aviation hazards. This section assessed the maturity of the ATM-impact models presented, and identified gaps in technologies that must be addressed for NextGen.

ANSP needs are associated with weather impact on traffic flow and airspace constraints; AOC/FOC needs are associated with weather impact on system-wide airline operations (e.g., connecting flights); flight deck needs are associated with weather impact on current operation such as safety and comfort. As noted in paragraph 1.3, AOC/FOC and flight deck decisions unique to the operator (i.e. excluding ANSP participation) are not a subject for intervention in the Plan. Those are principally left for market innovation to develop and implement.

By 2023, weather information will be integrated into decision making, but weather per se will not appear in the output decision at all. Whether the output decision takes the form of a human-readable display, or is relayed to a larger decision support mechanism, automated integration basically renders weather transparent to NextGen decision makers. Probabilistic weather data will introduce more complexity; e.g. the DST will have to compare input risk tolerance to probabilities of occurrence of the relevant weather phenomena in order to render a decision-quality output. For instance, a particular flight may be able to tolerate a 30% probability of thunderstorms along the planned route of flight, but it could not tolerate a 70% probability, in which case alternatives would be sought.

The expectation is that the number, complexity, and sophistication of automated DSTs will increase over time as the 4D Wx Data Cube matures, expanding its available sets of gridded data. At present the number of automated decision tools in the NAS is fairly limited, with inputs provided by point-to-point weather data feeds. As the 4-D Wx Data Cube assimilates grids of all meteorological parameters relevant to aviation, developers will build DSTs tailored to the particular needs and decision spectra of particular users. Development of tailored DSTs will be largely the province of the commercial sector where there is tremendous opportunity for ingenuity in applying weather to a whole range of decisions. The prime requirement for the weather community is that the weather information available by subscription from the 4D Wx Data Cube be in a form, at a resolution and at a quality level that meets user needs and can be readily translated into impacts and assimilated by the users' DSTs. In order for this integration to be successful, Human Factors research needs to be conducted to ensure that developers understand how weather is used in decision making so that the impact of weather data can be correctly translated into DSTs. This research will also be critical in determining the level or amount of weather transparency needed given the user's role in decision making. In some cases, anomalies or special circumstances may require users to view weather products as opposed to DST output.

2.2 Weather Impacts on Solution Sets

This plan addresses weather integration in terms of six of the NextGen OEP Solution Sets;

- Initiate Trajectory Based Operations (TBO)
- Increase Arrivals/Departures at High Density Airports (HighDensity)
- Increase Flexibility in the Terminal Environment (FlexTerm)
- Improved Collaborative Air Traffic Management (CATM)
- Increase Safety, Security and Environmental Performance (SSE)

Transform Facilities (Facilities)

Weather impacts the operational improvements of the solution sets in several ways, depending on the type of decisions being considered and its time horizon in the life cycle of a flight or a traffic flow. The integration of weather and ATM decisions can span from strategic pre-planning decisions to real-time tactical decision-making.Specific weather impacts are discussed in more detail in Section 3 and in Appendix A.

2.3 Alternatives Considered for Integration

The NextGen Weather concept of operations (ConOps) team recognized the need to look at improving the weather information infrastructure before it could be incorporated into the ATM decision support processes. This section briefly discusses three alternative approaches to weather integration. The emphasis of this discussion is on weather integration itself. The source of weather data (4-D4-D Wx Data Cube) and the network infrastructure that will distribute this information are considered separately.

Table 2-1 Alternatives Considered for Providing Weather Information

Alternatives	Description	Feasibility	Ability to Deliver NextGen Vision
Status quo – do nothing	Maintain current stand-alone text and graphical weather products	Green	Red
Improve Weather Products to Enhance Usability by ATM	Overlay weather data on to ATM displays and develop new weather displays with “high glance value”	Green	Yellow
Integrate Weather Information into ATM Decision Support Tools	Leverage net-centric standards and incorporate on-going research into weather impacts to add new weather algorithms to existing and developing TFM decision support tools.	Green	Green

2.3.1 Status Quo – Do Nothing

There are currently very few instances of the integration of weather data into ATM tools. Flight planning systems incorporate winds aloft and temperatures. Some tools are available involving the timing of deicing. Generally, weather is used manually, with stand-alone tools and displays. This situation requires controllers and decision makers to consult several unrelated displays in a manual mode in order to make critical decision. As stated earlier, weather accounts for more than 70% of flight delays. The current system is inadequate to mitigate this problem.

The baseline, multi-agency weather data processing, access, and dissemination architecture consists of multiple distributed processing systems collecting sensor data and producing value-added analysis and forecast products. Organizations access the data by approaching weather

processing systems and agency telecommunication systems to arrange for point-to-point transport of the weather products. Some data is also available via access to special web pages (e.g., Aviation Digital Data Service [ADDS]). The status quo is an unacceptable option because it involves diverse architectures, technologies, and standards; it does not meet numerous NextGen requirements (e.g., publication/subscription registry, push/pull access, tailored information, and a single authoritative source of weather information).

By maintaining the status quo, integration and automation would not be achieved.

2.3.2 Improve Weather Products to Enhance Usability by ATM

The second alternative considered is to improve current weather products in ways that improve their usability by TFM decision makers. Weather information can be overlaid on air traffic displays and weather displays can be upgraded to reduce the amount of interpretation required for rapid understanding of the weather situation. These “high glance value” displays reduce TFM decision-makers’ requirement to have a deep understanding of weather situations.

This alternative can be accomplished without general improvements to the underlying weather delivery systems; however, significant improvements are required in weather processing to achieve reductions in avoidable delays. This alternative would not achieve NextGen goals nor would it allow for improvements in TFM tools such as TMA which now require the tool to be turned off during adverse weather because of lack of weather integration. Accordingly, the integration of a common weather picture into all of the ATM decision support systems and planned automation systems would not be achieved.

2.3.3 Integrate Weather Information into ATM Decision Support Tools

The last alternative is to integrate weather information into ATM decision support tools. This alternative meets the goals and recommendations set out by the Weather – ATM Integration Working group of the national Airspace Systems Operations Subcommittee, Federal Aviation Administration Research, Engineering and Development Advisory Committee (REDAC) in their report dated October 3, 2007. A key finding of this report “is that a risk management approach with adaptive, incremental decision making, based on automatically translating weather forecasts into air traffic impacts, presents a major new opportunity for reducing weather related delays in the future NAS.” Achievement of this alternative requires development of a new weather data architecture by heavily leveraging net-centric standards and incorporating legacy architectures. This option overcomes the deficiencies of the other alternatives, meets all NextGen goals and requirements, is the most cost effective, and involves acceptable implementation risk. It also allows for the provision of current regulatory weather products (e.g., convective Significant Meteorological Information [SIGMETS]), while policy is changed to transition the NAS from a ‘product’ to an ‘information’ environment. This option includes distributed data processing, with centralized publication/subscription, using much of the current baseline architecture; and develops a single authoritative source of weather information for collaborative decision making involving ground and airborne platforms. The underlying architecture developed to achieve NextGen goals provides the necessary platforms and capabilities for the integration of weather information directly into DSTs.

2.4 Recommended Solution: Integrate Weather into ATM Decision Support Tools

The recommended solution is to integrate weather directly into ATM Decision Support Tools. Weather integration will simplify the decision process for humans and make weather data seamless to NAS users. Weather integration allows user decision tools to have the best available weather information and to use that information in a wide range of decisions both on the ground and in the cockpit.

The 4-D4-D Wx Data Cube is not part of this plan, however, this alternative assumes the existence of the 4-D4-D Wx Data Cube, a virtual database of information - separate weather databases located in different locations such as National Weather Service (NWS), other Agency processing facilities, research or laboratories, etc. and connected via a net-centric infrastructure. Rapid updates of weather data used in TFM tools is essential to successful weather integration and therefore, the underlying infrastructure being developed for NextGen is key to the success of the weather integration effort. The 4-D4-D Wx Data Cube is essential to the development of DSTs which integrate weather directly into the decision making process.

2.5 Anticipated Benefits and Impact

Advances in weather information content and dissemination provide users and/or their decision support with the ability to identify specific weather impacts on operations (e.g., trajectory management and impacts on specific airframes, arrival/departure planning) to ensure continued safe and efficient flight. Users will be able to retrieve (and subscribe to automatic updates of) weather information to support assessment of flight-specific thresholds that indicate re-planning actions are needed. In particular, the 4D Wx Data Cube (and later The 4D Weather Single Authoritative Source (4D Wx SAS)) will support enhanced volumetric extractions, by time frame of interest, of weather information by NAS users to quickly filter the enhanced weather content to the region of interest for impact analysis. This will streamline the process by which the user with decision support ATM tools - conducts system-wide risk management in planning for both individual flight trajectories and flows.

Because of the profound impact of adverse weather on the safety, efficiency, and capacity of the NAS, improved decision making when weather impacts operations is a key NextGen objective. The initial 4D Wx SAS, a subset of the 4D Wx Data Cube, provides a consistent, de-conflicted common weather picture (e.g., observations, forecasts, and climatology, from the surface to the top of the NAS) that will provide Air Navigation Service Providers (ANSPs) and airspace users with a common view of the weather situation.

Using the 4D Wx SAS, ANSPs, users and their decision support systems will be able to make trajectory-oriented or area-oriented requests for weather information so that they can determine its effect on the flight trajectory being evaluated. This customized weather information will be integrated into initial tactical and strategic decision support tools developed under the TBO, CATM, Flexible Terminal, and High Density Terminal solution sets. These tools will assess the risk management of the operational impact of weather on flights/trajectories and provide candidate actions to the ANSP that mitigate these impacts on safety and traffic flow. These tools

support real time "what if" assessments, support common situation awareness within and between domains, and can be tailored to support different user preferences (e.g., displays, lists, alert modes, flight specific probabilistic thresholds, and format tailoring). The 4-D Wx SAS provides a single and authoritative definition of the current weather state and prediction of the future weather, as well as the user-requested high resolution, high temporal characteristics of importance to aviation users. The 4D Wx SAS will also provide proactive updates ("push") to requestors based on user requests.

The combination of consistent weather information integrated into decision support tools will enable more effective and timely decision making by both ANSPs and users, for meeting capacity, efficiency and safety objectives. This also supports the alignment of traffic flows that best achieve a balanced capacity, safety and end user desires. It effectively enables a common understanding of the uncertainty of the future state of the atmosphere, supports traffic flow management by trajectory, and provides for improved weather avoidance.

3 NEXTGEN WEATHER INTEGRATION: DECISION SUPPORT TOOLS

This section contains an analysis of the need and opportunity for weather integration into NAS operations. This section and its associated Appendix A are to be expanded and refined as more information becomes available through execution of the Plan. Until more facts are known about the target capabilities, the section will rely on appropriate assumptions on the kinds of weather information required for integration into decision support tools and capabilities. It is aimed at ATO solution sets as defined in the NextGen Implementation Plan (NIP): Initiate Trajectory Based Operations (TBO), Increase Arrivals/Departures at High-Density Airports (High Density), Increase Flexibility in the Terminal Environment (Flex Term), Improved Collaborative Air Traffic Management (CATM), Increase Safety, Security, and Environmental Performance (SSE), and Transform Facilities (Facilities).

Each solution set was broken down into swim lanes and then further into Capabilities and associated Operational Improvements (OIs). Capabilities fell within either the Near, Mid, or Far-Term time frame as consistent with the solution set. Where possible, an assessment of each capability was done with reference to its link to weather and current developments, from the exploration (CE) to development (CD) to prototype (PD) phase. Beginning with a set of assumptions the value of integrated weather was examined within the context of an overarching scenario or concept of operations. The scenario was further broken down into individual use cases, where possible, to help define and draw out user needs and points of integration. Decision support tools, information threads, and weather linkages were closely examined, where possible to fully inform the integration solution. The work is iterative and will require continued effort as time, resources and understanding evolve.

The information for each solution set below follows the same general flow as mentioned above, with minor variances due to inherent differences in individual solution sets.

The expected weather and weather integration requirements of the capabilities were extracted from several different sources, including the REDAC Weather/ATM Integration report, the JPDO Weather Integration Conference report, the MITRE Initial Evolution Analysis for Achieving NAS Mid-term Operations and Capabilities report, the MIT/LL Roadmap for Weather integration into Traffic Flow Management Modernization report, the FAA Traffic Flow Management Concept Engineering Plan FY09 and the FAA Infrastructure Roadmap – Mid-term Integration Worksheets.

Beyond this, additional commentary, analysis, or planning information was added. Interviews with JPDO WG Subject Matter Experts and FAA Solution Set Coordinators, to the extent possible, helped to extract additional capability/weather information. Assumptions were written based on viewpoints of the three Collaborative Decision Making (CDM) participants (Aircraft, Airline Operations Control, and Air Traffic Control). In some cases, scenarios were created in which the use of weather information in support of the mid-term capability was explored.

General Assumptions

One of the assumptions associated with all the solution sets is that near-term stand-alone decision tools will begin to move from the current state of little to no weather integration to being fully

integrated with weather (including uncertainty) in the far-term. Specifically, four levels of weather integration are expected:

Level 1 Stand alone (little to no weather integration)

Level 2 Over-lapping (high "glance value" weather impact information overlaid with decision support tool outputs)

Level 3 Minor human involvement (user-in-the-loop tools: Weather fully integrated within tool but separate weather information also provided for human understanding)

Level 4 Fully integrated (machine-to-machine: Weather and uncertainty fully integrated into decision tool outputs)

Another assumption is that weather is addressed for all temporal and spatial operational needs for all airspace from strategic planning and risk assessment to the tactical environment that surrounds, or is on the airport surface.

Solution Set Representation

Section 3.1, Trajectory Based Operations (TBO), identifies and briefly describes potential TBO weather integration opportunities, based on an on-going discussion of the mid-term OIs contained in the Initiate TBO solution set. Appendix A-1 defines key terms (TBO, Initiate TBO, 4D Trajectory); documents OI goals, needs/shortfalls, descriptions, and design/architecture; contains a discussion of the Initiate TBO solution set OI descriptions; describes weather integration opportunities in more detail; develops weather integration scenarios; and identifies potential mid-term functional weather requirements. This is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Initiate TBO solution set. The mid-term OIs included in the Initiate TBO solution set are:

f) Delegated Responsibility for Separation
g) Oceanic In-trail Climb and Descent
h) Automation Support for Mixed Environments
i) Initial Conflict Resolution Advisories
j) Flexible Entry Times for Oceanic Tracks
k) Point-in-Space Metering
l) *Flexible Airspace Management*

- *Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP)*

The Increase Arrivals/Departures at High Density Airports (High Density) solution set involves airports (and the airspaces that access those airports) in which:

- Demand for runway capacity is high;
- There are multiple runways with both airspace and taxiing interactions, or;
- There are close proximity airports with the potential for airspace or approach interference.

High density airports require all the capabilities of flexible terminals and surrounding airspace plus integrated tactical and strategic flow capabilities. Decision support tools may require higher performance navigation and communications capabilities, including higher fidelity weather information for integration, for air traffic and the aircraft to support these additional operational requirements. High density corridors will serve as transitions to and from trajectory-based en-route airspace. High density operations will seamlessly integrate surface operations through transition altitudes to en-route airspace.

The Flexible Terminal solution set has a focus on improvements to the management of separation at all airports. Such capabilities will improve safety, efficiency and maintain capacity in reduced visibility high density terminal operations. At airports where traffic demand is lower, and at high density airports during times of low demand, operations requiring lesser aircraft capability are conducted, allowing access to a wider range of operators while retaining the throughput and efficiency advantages of high density operations. Both trajectory and non trajectory-based operations may be conducted within flexible terminal operations.

The Collaborative Air Traffic Management (CATM) solution set covers strategic and tactical flow management, including interactions with operators to mitigate situations when the desired use of capacity cannot be accommodated. This solution set includes flow programs and collaboration on procedures that will shift demand to alternate resources (e.g. routings, altitudes, and times). CATM also addresses the management of aeronautical information necessary for all operations within the NAS, including the management of airspace reservation and flight information from pre-flight planning to post-flight analysis.

A summary of results is given here, with more details presented in Appendix A.

3.1 Trajectory Based Operations

This section is a summary of Appendix A, section A-1. The paper on TBO found in A-1 is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Initiate Trajectory Based Operation (TBO) solution set. Mid-term Operational Improvement (OI) descriptions, contained in this paper, go somewhat beyond what current NextGen and Federal Aviation Administration (FAA) documentation provide. The reason for this is to develop a more complete understanding of these OIs, so mid-term weather integration candidates can be more easily identified. Although these extensions to mid-term capability descriptions have not yet received review and vetting, this paper provides a vehicle by which these assumptions can obtain needed feedback, thereby furthering our understanding of mid-term OIs. These mid-term OIs begin the journey towards a full NextGen capability. This document describes these initial steps and their future evolution.

The purpose of A-1 is to support drafting of the Joint Planning and Development Office's (JPDO) Air Traffic Management (ATM) Weather Integration Plan by:

- Identifying and describing likely Traffic Flow Management (TFM) by trajectory weather integration opportunities based on the mid-term OIs contained in the Initiate TBO solution set and

- Developing weather integration scenarios to help identify potential mid-term functional weather requirements.

Section A-1 may also be useful in supporting other activities such as the:

- Refinement of OI descriptions in the Initiate TBO solution set,
- Scenario development by the FAA's Implementation and Integration (I&I) team,
- Drafting of en route TBO white papers by the JPDO's Air Navigation Services (ANS) Working Group (WG), and
- Drafting of TBO Concept of Operations (ConOps) and Concept of Use (ConUse) documents.

To-date, the following mid-term, Initiate TBO, weather-related, operational capabilities have been identified as 'potential' candidates for inclusion into decision support tools (DSTs). More analysis and discussion are required before a final set can be presented. From among these weather integration candidates, some may be incorporated into TBO ConOps documents, forming the basis for NextGen weather integration requirements.

Initial Conflict Resolution Advisories

- Controller weather problem detection decision support to:
  - Prevent directing aircraft into hazardous weather inadvertently when resolving aircraft-to-aircraft conflicts
  - Evaluate a pilot requested maneuver around the weather to ensure it will not send the aircraft into another area of convection not yet visible on the aircraft's airborne radar
- Controller weather problem resolution decision support to respond to pilot requests for assistance to:
  - Route around significant areas of convective weather that are rapidly and unexpectedly worsening
  - Return aircraft to original flight plan when convective weather rapidly and unexpectedly improves

Flexible Entry Times for Oceanic Tracks

- Integrate oceanic wind forecast information with the calculation of flexible entry times for oceanic tracks

Point-in-Space Metering

- Calculation of a sequence of recommended upstream Controlled Times of Arrival (CTAs) to a downstream capacity-constrained point, integrating weather and aircraft

performance information, and conversion of these CTAs into desired airspeed changes

Flexible Airspace Management

- Determination of pre-defined airspace configurations, using existing traffic patterns and climatological weather
- Identification of airspace needs and development of a baseline plan for the given flight day, 1 to 5 days ahead, using forecasted weather information
- Establishment of a baseline airspace configuration for the day, 8-24 hours in advance, using forecasted weather information
- Determination of alternative airspace configurations, 4-8 hours in advance, using forecasted weather information
- Selection and implementation of specific airspace configuration alternatives, 1- 4 hours in advance, using forecasted weather information

Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigational Performance (RNP)

- Determination of whether fixed RNAV/RNP routes are or soon will be blocked by convective weather

Additionally, the following mid-term, en route TBO, weather-related, operational decisions have been identified as 'potential' candidates for common weather situational awareness among decision makers:

Delegated Responsibility for Separation

- Delegated responsibility for pair-wise separation in convective weather (i.e., aircraft following a 'pathfinder')

Initial Conflict Resolution Advisories

- Controller vectors an aircraft around a convective weather cell with an open-loop clearance.

3.2 High Density Airports

This section is a summary of Appendix A, section A-2. The paper on High Density Airports found in A-2 is a work in-progress intended to help communicate and refine the developing mid-term weather integration story for the Increase Arrivals/Departures at High Density Airport solution set. Mid-term Operational Improvement (OI) descriptions, contained in this paper, go somewhat beyond what current NextGen and Federal Aviation Administration (FAA) documentation provide. The reason for this is to develop a more complete understanding of these OIs, so mid-term weather integration candidates can be more easily identified. Although these extensions to mid-term capability descriptions have not yet received review and vetting, this paper provides a vehicle by which these assumptions can obtain needed feedback, thereby

furthering our understanding of mid-term OIs. These mid-term OIs begin the journey towards a full NextGen capability. This document describes these initial steps and their future evolution.

The purpose of A-2 is to support drafting of the Joint Planning and Development Office's (JPDO) Air Traffic Management (ATM) Weather Integration Plan by:

- Identifying and describing likely high density airport weather integration opportunities based on the mid-term OIs contained in the Increase Arrivals/Departures at High Density Airports solution set and
- Developing weather integration scenarios to help identify mid-term functional weather requirements.

Section A-2 may also be useful in supporting other activities such as the:

- Refinement of OI descriptions in the Increase Arrivals/Departures at High Density Airports solution set,
- Scenario development by the FAA's Implementation and Integration (I&I) team,
- Drafting of high density airport white papers by the JPDO's Air Navigation Services (ANS) Working Group (WG), and
- Drafting of Increase Arrivals/Departures at High Density Airports Concept of Operations (ConOps) and Concept of Use (ConUse) documents.

To-date, the following mid-term, weather-related, operational decisions for Increase Arrivals/Departures at High Density Airports have been identified as 'potential' candidates for inclusion into decision support tools (DSTs). More analysis and discussion are required before a final set can be presented. From among these weather integration candidates, some may be incorporated into Increase Arrivals/Departures at High Density Airports ConOps documents, forming the basis for NextGen weather integration requirements.

Integrated Arrival/Departure Airspace Management

- Support/recommend a stable, baseline arrival/departure configuration plan for the flight day
- Proactively support/recommend arrival/departure configuration modifications, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to new arrival/departure configurations
- Reactively support/recommend arrival/departure configuration modifications in response to rapidly changing and highly localized weather conditions (e.g., pop-up thunderstorms on arrival/departure routes)

Time-Based Metering Using RNP and RNAV Route Assignments

- Calculation of a set of 'attainable' Controlled Time of Arrivals (CTAs) to an arrival metering fix, taking weather's impact on aircraft speed and performance into account
- Improve departure routing, by increasing the accuracy of predicted trajectories

Initial Surface Traffic Management

- Support/recommend a stable, baseline airport configuration plan for the flight day
- Proactively support/recommend airport configuration modifications, far enough in advance of predicted weather (e.g., wind shift), to efficiently move traffic to new airport and arrival/departure configurations
- Support/recommend surface sequencing and staging lists and determine (current and predicted) average departure delays

3.3 Flexible Airspace in the Terminal Area

3.3.1 Separation Management

Wake Turbulence Mitigation for Departures (WTMD) - Wind-Based Wake Procedures relies on improved wake vortex (WV) prediction capabilities, and the integration of that WV information into display systems and decision support tools (DSTs) which identify and mitigate the impact of wake turbulence generated by one aircraft on a following aircraft. As compared to the generalized methodologies employed today, this flight pair-specific approach to dealing with wake turbulence should allow for the reduction of spacing between aircraft, thereby improving runway capacities across a range of weather conditions and operating regimes. Implicit in this statement is that existing wake vortex-based separation rules will be changed based on the capability of WTMD-based systems to predict the transport or decay of wake vortices and their precise impact on the trailing aircraft.

Although this Operational Improvement (OI) specifically focuses on wake mitigation in the departure regime, and is therefore assumed to be concerned primarily with longitudinal separation between departing aircraft, there is also the need for similar capabilities in the arrival regime, and especially for arrivals to Closely Spaced Parallel Runways (CSPRs). It is almost certain that the display systems and DSTs created to provide Wake Turbulence Mitigation for Arrivals (WTMA) will require the same weather inputs as will procedures and DSTs designed to provide WTMD, despite the fact that the resultant arrival processes are likely to be concerned with the lateral, instead of longitudinal, separation of aircraft landing on adjacent runways. See Appendix A-2.3, Improved Operations to Closely Spaced Runways, for additional WTMA discussion in the context of closely spaced parallel runways.

WTMD and WTMA display systems and DSTs are likely to depend on the integration of real time local wind data and high resolution, high refresh wind profile forecasts into a wind forecast algorithm, whose output in turn will then need to be integrated into the appropriate wake turbulence mitigation processing function. Based on the precision required of WTMD and WTMA DSTs, it is thought that enhanced forecasts of terminal winds will be needed, thus creating high temporal and spatial wind observation and reporting requirements.

m) WTMD/WTMA weather integration is envisioned to mean that high resolution, real time local wind data and high resolution, high refresh rate wind forecasts are part of a wind forecast algorithm which in turn is integrated into the WTMD/WTMA processing function.

n)

- o) ˜ ATC policies and procedures will have to be changed to allow differing separation criteria based on information from wake turbulence mitigation models, regardless of whether the separation criteria are calculated and assigned manually or automatically.

- Integrated Work Plan (IWP) enablers (i.e., EN-0029 and EN-0030) describe a ground-based wake vortex advisory system that presumably includes high spatial and temporal wind observations and whose sole focus is on wake vortex detection, prediction and aircraft spacing guidance in the terminal area – especially for impacts to operations on CSPR. It has been estimated in the NextGen Portfolio Work Plan on Resource Planning Data (RPD) that several additional departures per hour from closely-spaced parallel runways are possible, if the dissipation of the wake turbulence can be predicted. Regardless of where or how weather information is integrated, the net effect on improved operations will be driven by changes in separation standards and procedures.

Ground-Based Augmentation System (GBAS) Precision Approaches will support precision approaches to Category I (as a non-federal system), and eventually Category II/III minimums for properly equipped runways and aircraft. GBAS can support approach minimums at airports with fewer restrictions to surface movement and offers the potential for curved precision approaches. GBAS also can support high-integrity surface movement requirements.

GBAS increases the accuracy of position information from GPS/GNSS satellites to a level appropriate to the procedure being conducted. Like any system which relies on radio wave communications through the atmosphere, the performance capability of GBAS may be affected by significant solar activity. Consequently, it is possible that components of a GBAS and onboard systems which utilize GBAS may have to include information on the start and end times, expected duration, intensity and anticipated impact of solar activity on the accuracy of the system.

3.3.2 Trajectory Management

Optimized Profile Descents (OPDs) (also known as Continuous Descent Arrivals -- CDAs) will permit aircraft to remain at higher altitudes on arrival at the airport and use lower power settings during descent. OPD arrival procedures will provide for lower noise and more fuel-efficient operations.

The integration of high resolution terminal winds into aircraft equipped with onboard energy management guidance systems may allow these aircraft to fly precise 4DTs that are highly optimized for fuel efficiency. Minimally equipped aircraft, in contrast, may fly a more basic OPD that simply applies idle thrust wherever possible. In addition, the precise 4DT flown by an aircraft on an OPD will vary by a number of factors including winds aloft, aircraft weight, and top of descent point.

Although this capability focuses on the need for accurate winds aloft data for OPD operations, pilots and controllers will need more information in order to consistently plan and complete OPDs, such as improved observations and forecasts of winds and hazards to aviation such as convectively induced turbulence (CIT), clear air turbulence (CAT), lightning and hail. Further

investigation of these weather factors, any or all of which can impact OPD operations, and how to integrate them into OPD-related decision support tools, needs to be undertaken in order to improve OPD planning and operations.

To that end, existing airborne capabilities of measuring wind, turbulence, temperature, humidity and icing need to be improved and fully leveraged. Processes which enable and encourage the transmission of this information to ground systems and adjacent aircraft must be developed, and then that information must be incorporated into weather forecast models and ATM and onboard decision support tools as appropriate.

It would seem that the eventual migration of the Descent Advisor functionality would be the likely target for weather integration of high resolution terminal winds and wind shear zones. Tools that help determine compression spacing needs would also likely need similar weather information integration.

3.3.3 Flight and State Data Management

Provision of Full Surface Situation Information will involve automated broadcasts of aircraft and vehicle positions to ground and aircraft sensors/receivers. This information will then be used to populate a digital display of the airport environment. Aircraft and vehicles will be identified and tracked, providing a full comprehensive picture of the surface environment to the Air Navigation Service Provider (ANSP), equipped aircraft, and AOC/FOCs.

Decision support tool (DST) algorithms will use this enhanced target data to support identification and alerting of those aircraft at risk of runway incursion. This surface situation information will complement visual observation of the airport surface. Service providers, AOC/FOCs, and equipped aircraft need an accurate real time view of airport surface traffic and movement, as well as obstacle location, to increase situational awareness of surface operations. Currently, this can be difficult because of several factors, including, but not limited to poor visibility caused by weather or nighttime conditions.

Enhanced Surface Traffic Operations involve data communication between aircraft and Air Navigation Service Provider (ANSP) and is envisioned to be used to exchange clearances, amendments, requests, NAS status, weather information, and surface movement instructions. At specified airports data communications is the principal means of communication between ANSP and equipped aircraft. Among the information being sent to the aircraft and integrated into on-board aircraft systems will be On-Demand NAS Information from the Super Computer Aided Operational Support System (S-CAOSS), the tower platform for Data Comm Program Segment 1 (e.g., OI 103305 for 2013-2017). Terminal aeronautical information will be available to equipped aircraft and provided on demand via data communications between the FAA ground automation and the aircraft. This includes current weather, altimeter settings, runways in use, and other departure and destination airport information.

This initiative has a communications focus aspect – not necessarily the weather information aspect. However, there needs to be adequate bandwidth provided for the communication of weather information so that it can then be integrated. It is understood that other informational sources will command higher availability. To this extent, advanced on-board Flight Management

Systems, integrated with surface weather conditions need to be coupled with the broadcast of aircraft position, state, and intent information. There is a need to assist air traffic controllers to clear aircraft to follow other aircraft on the cockpit display on an approach, at separation minimums much less than those that are applied today in bad weather.

3.4 Collaborative Air Traffic Management

3.4.1 Flight Contingency Management

Continuous Flight Day Evaluation concepts involve ANSPs and users to collaboratively and continuously assess (monitor and evaluate) constraints (e.g., airport, airspace, hazardous weather, sector workload, Navigational Aid (NAVAID) outages, security) and associated TMI mitigation strategies. Performance analysis, where throughput is constrained, is the basis for strategic operations planning. Continuous (real time) constraints are provided to ANSP traffic management decision support tools and National Airspace System (NAS) users. Evaluation of NAS performance is both a real time activity feedback tool and a post-event analysis process. Flight day evaluation metrics are complementary and consistent with collateral sets of metrics for airspace, airport, and flight operations.

Mid-term continuous flight day evaluation with integrated weather supports performance analysis and improvement capabilities, congestion prediction and decision-making, and enhanced post operations analysis. Capacity prediction improvements especially are a significant enhancement for TFM in the mid-term, with the most value resulting from the integration of weather prediction information (uncertainty). This will allow weather information to be used not only in capacity predictions, but in demand prediction and aircraft trajectory modeling displays as well, further improving the TMs understanding of NAS status and managed risk. Later in the mid-term, automation will predict sector capacity based on traffic flows and weather predictions instead of using the Monitor Alert Parameter as a proxy for sector capacity. Mitigation of congestion will be supported by TFM automation which will disseminate probabilistic (integrated weather uncertainty) demand and capacity predictions for all monitored NAS resources to TMs and NAS customers.

It was concluded that weather integration may additionally have a role in the support of the following Traffic Flow Management concept engineering CATM-related Mid-Term initiatives:

- Enhanced Flight Segment Forecasting
- Airborne Delay Research
- Integrated Program Execution (IPE)
- Integrated Program Modeling (IPM) Phase 2
- NextGen of FSM slot assignment logic
- Pre-day of Operations TFM concepts
- System Integrated TMI’s
- Analyze Uncertainty in Sector Demand Prediction

- Prototype a New Metric for Sector Alerts

Traffic Management Initiatives with Flight-Specific Trajectories (Go Button) refers to individual flight-specific trajectory changes resulting from Traffic Management Initiatives (TMIs) will be disseminated to the appropriate Air Navigation Service Provider (ANSP) automation for tactical approval and execution. This capability will increase the agility of the NAS to adjust and respond to dynamically changing conditions such as bad weather, congestion, and system outages.

Decision support tool functionality that support this capability will require integration of probabilistic information, management of uncertainty, what-if analysis, and incremental resolution of alternatives supporting development and implementation of flexible, incremental traffic management strategies to maintain the congestion risk to an acceptable level and to minimize the impact to the flights involved in the congestion.

3.4.2 Capacity Management

Improved Management of Airspace for Special Use includes assignments, schedules, coordination, and status changes of special use airspace (SUA) are conducted machine-to-machine. Changes to status of airspace for special use are readily available for operators and Air Navigation Service Providers (ANSPs). Status changes are transmitted to the flight deck via voice or data communications. Flight trajectory planning is managed dynamically based on real time use of airspace.

The need for weather integration is envisioned to be similar to that for flight contingency management with an emphasis on more effective informational exchange between TFM and NAS users. Coordination between civilian NAS users and military NAS users regarding weather impacts and the availability of SUAs is particularly important. Weather informational needs will include predicted weather constraints (e.g. convection, turbulence, ceiling/visibility or runway winds limitations at an airport), estimates of weather uncertainty, and quantitative, time-varying forecasts of the reduction in NAS resource availability due to the weather.

Informational exchange between TFM and controllers, including Tower/TRACON supervisors and en-route area managers would benefit from broad-area depictions of weather-related constraints in place, forecasts of future constraints and an effective means of collaborating with their facility's Traffic Management unit in developing tactical response strategies for these constraints. National TM personnel should have improved visibility into weather constraints affecting the tactical environment in key en-route and terminal facilities.

3.4.3 Flight and State Data Management

Trajectory Flight Data Management improves the operational efficiency and increases the use of available capacity by providing for improved flight data coordination between facilities. This will enable access to airports by readily facilitating reroutes. Additionally, it will support more flexible use of controller/capacity assets by managing data based on volumes of interest that can be redefined to meet change to airspace/routings. Trajectory Flight Data Management will also provide continuous monitoring of the status of all flights – quickly alerting the system to unexpected termination of a flight and rapid identification of last known position. Weather

integration can support this capability and likely will consist of improved observations, enhanced forecasts and a de-conflicted common weather picture.

It was concluded that weather integration may additionally have a supporting role in the following Traffic Flow Management concept engineering CATM-related Mid-Term initiatives:

- Additional AFP capabilities and usage
- Environmental modeling and analysis of TFM performance (fuel burn estimation)
- Reroute impact assessment
- Special use airspace information research

Weather integration in support of common flight profiles may have value for functions that determine trajectory changes and problem predictions/resolutions (aircraft-to-aircraft, aircraft-to-airspace, aircraft-to-TFM Flow Constraint, Aircraft-to-Severe Weather).

The functional evolution Traffic Management Advisor (TMA) is a candidate for weather integration since the TMA is envisioned to continue in operation at several locations that are frequently impacted by convective weather. The integration of weather products into TMA is underway.

<u>Integrated Time-Based Flow Management (ITBFM)</u> will provide traffic managers an improved capability to develop, execute and adjust a common and integrated departure-to-arrival schedule for all aircraft that supports both TFM objectives and, to the extent possible, NAS customer preferences. There may well be differences in the details of the weather forecast translation into ATC impacts for DFM versus TMA. Hence, it will be important to determine the anticipated mode of operation for ITBFM so as to determine if there are additional weather-to-capacity translation issues that need to be considered in achieving an operationally useful ITBFM.

<u>Provide Full Flight Plan Constraint Evaluation with Feedback</u> involves timely and accurate NAS information that allows users to plan and fly routings that meet their objectives. Constraint information that impacts proposed flight routes is incorporated into Air Navigation Service Provider (ANSP) automation, and is available to users for their pre-departure flight planning. Examples of constraint information include special use airspace status, significant meteorological information (SIGMET), infrastructure outages, and significant congestion events. Weather needs identified include a common weather picture of enhanced forecasts of convection, turbulence and icing. Improved observations are also needed.

Specifically the feedback will include weather information, probabilistic information, TMIs (including delay information), airspace information (e.g., High Performance Airspace (HPA)/Mixed Performance Airspace (MPA), Area Navigation (RNAV) routes), required aircraft performance characteristics (e.g., Required Navigation Performance (RNP), RNAV requirements), active routes, restrictions (e.g., Letter of Agreements (LOAs), Standard Operating Procedures (SOPs), Special Activity Airspace (SAA)), terminal status information (e.g., airport conditions, runway closures, wind, arrival rates, Runway Visual Range (RVR), airport (current and planned) configurations, surface information and other NAS status information and changes along the path of the evaluated route or filed route.

Realizing a robust capacity prediction capability will require major effort in at least three areas. Continued progress in diagnosing and forecasting relevant weather phenomena over the 0-24 hour time scales needed for TFM is essential. Research may be focused on extending the look-ahead-time for convective weather forecasts to 6-24 hours, and on improved 0-2 hour "nowcasts" of turbulence and airport weather conditions (ceiling and visibility, winds, winter precipitation) that affect capacity. Viable methods for estimating and conveying the uncertainty of future resource capacity predictions must be defined. Dynamic capacity estimation models will need to consider weather in their capacity estimates.

On-Demand NAS Information means that National Airspace System (NAS) and aeronautical information will be available to users on demand. NAS and aeronautical information is consistent across applications and locations, and available to authorized subscribers and equipped aircraft. Proprietary and security sensitive information is not shared with unauthorized agencies/individuals. Dynamic NAS status information includes current weather constraints and SIGMETs. As mentioned before for other CATM capabilities, weather integration will need to be accompanied by a de-conflicted common weather picture and made available for TFM and AOC/FOCs.

3.5 Increase Safety, Security and Environmental Performance (SSE)

3.6 Transform Facilities (Facilities)

3.7 Additional Initiatives and Targets:

The System Enhancement for Versatile Electronic Negotiation (SEVEN) initiative involves rerouting flights. This can be a manually intensive, time and attention-consuming effort while giving little consideration to NAS customer input. SEVEN provides a concept for managing en-route congestion that allows NAS customers to submit prioritized lists of alternative routing options for their flights. SEVEN has the potential to reduce traffic manager workload, while allowing better traffic control in uncertain weather situations.

Traffic managers can assess the impact of various flight plan options on system congestion using an Interactive Dynamic Flight Lists (IDFL) and choose an option from the customer submitted list that provides weather avoidance and meets airspace capacity constraints. The utility of this concept when it is used to mitigate weather impacts on NAS customers will vary substantially from case to case, depending on the weather forecasts, which is a function of the type of weather and the look-ahead-time, the ability to accurately estimate NAS resource constraints from these forecasts, and the sophistication of the customer's process for utilizing this information to define and prioritize alternatives for the impacted aircraft.

4 TECHNOLOGY AND METHODOLOGY CONCEPTS

This section, with more detail in Appendix B provides a survey that identifies technologies and methodologies for translating weather information into Air Traffic Management (ATM) impacts

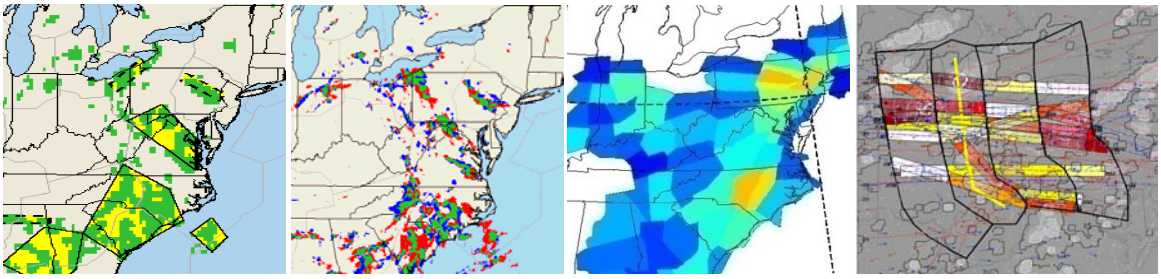
in the National Airspace System (NAS). The survey includes approaches for addressing weather-related uncertainty in ATM decision making – risk management processes. The survey is organized into two parts:

- ATM-Weather Impact Models – these describe the translation of weather information into ATM impacts as outputs, and
- ATM-Weather Integration Techniques – these describe how ATM-weather impact models may be integrated into Decision Support Tools (DSTs) or in other ways to manage uncertainties in NAS decision making.

For each part, the maturity of the state of the art is determined and gaps in technology are identified. These methodologies emphasize solutions for ATM-weather integration for the Next Generation Air Transportation System (NextGen).

4.1 Survey of ATM-Weather Impact Models

In the NAS, en route Traffic Flow Management (TFM) balances air traffic demand against available capacity, to ensure a safe and expeditious flow of aircraft. TFM resources may be expressed in terms of airspace availability; this includes fix availability, route availability, and airspace availability (e.g., grid cell, hex cell, sector, center, or Flow Constrained Area (FCA)). For example, Figure 4-1 illustrates the transformation of weather forecast data into point-impacts (suitable for assessing fix availability), route-impacts (suitable for assessing route blockage), and sector-based impacts (suitable for TFM flow planning). TFM resources also include airport resources, including Airport Arrival Rate (AAR), Airport Departure Rate (ADR), runway availability, and others. All these resources are important and are mentioned in the survey where applicable.



(a) Convective Forecast (b) Pixel-based impact (c) Sector-based impact (d) Route-based impact

Figure 4-1 Convective forecast transformed into ATM impact in various formats.

The majority of the ATM-impact models address airspace capacity issues. In today's NAS, there is no automation tool to predict airspace capacity, since there is no established and accepted indicator of airspace capacity. The Enhanced Traffic Management System (ETMS) [E02] provides a congestion alerting function which uses the peak one-minute aircraft count as a sector congestion alerting criterion (the Monitor Alert Parameter (MAP)). The MAP is not meant to be a measure of airspace capacity, but rather a threshold which, when exceeded by predicted demand, alerts traffic managers to examine the sector for potential congestion. The MAP value is

typically designed to account for the nominal traffic structure experienced in the airspace rather than a hypothetical structure designed to maximize capacity. ATM-impact models that address the structure from nominal routing along today's jet routes as well as ATM-impact models that design new traffic flow structures that maximize capacity are included in the survey, since it is clear that airspace capacity models are needed for today's routing structures as well as NextGen's more flexible routing structures.

As demonstrated by the survey, estimating capacity has many difficulties due to the complexity of weather forecasting and demand estimation. One difficulty is that weather forecasts all have some degree of uncertainty. To address this, several of the ATM-impact methods go beyond deterministic weather forecasts and into probabilistic weather forecasts, both in terms of probability distributions as well as ensemble weather forecasts. In addition to weather forecast errors, minor differences in how weather develops, for instance, the weather organization, can lead to major differences in the impacts on the NAS. Small storms located at critical locations in the NAS can have more impact than larger storms in less critical locations. In the case of a squall line, for instance, many of the westbound flights in a sector may be blocked, while several northbound flights can make it through. One ATM-impact method specifically addresses the issue of directional capacity. Furthermore, ATM-impact models for en route airspace must be modified to address transition or terminal area airspaces. Sector capacity in particular, is a function of the traffic flow pattern, whether it is a pattern established by jet routes, a uniform distribution of flow in a standard direction (e.g., East-to-West), or random, as is the case of Free Flight (if implemented in NextGen). Capacity is not strictly independent of demand; the trajectories and altitude profiles of flights that plan to use an airspace can significantly alter how many flights can be managed. Some researchers refer to this as "demand-driven capacity."

Next, we present a summary of each of the surveyed ATM-impact models starting with models that were derived primarily for convection, and ending with a wide variety of models for several types of aviation hazards, including turbulence, icing, winter weather, and others.

Empirical Methods. Empirical methods do not model capacity directly. They infer the capacity from historical traffic data and they infer the relationship between capacity reduction and weather by comparing historical traffic to weather data. This may be accomplished from a range of techniques from statistical testing to cluster analysis. Empirical methods may be applied to all types of weather, such as convective weather, turbulence, icing, ceiling and visibility, and surface winds. Also, empirical methods may be applied to assess the capacity of a wide variety of NAS resources, including metering fix capacity, route capacity, sector and center capacity, and even overall NAS capacity.

Rational Methods. Rational methods model capacity directly. They deduce the capacity from traffic models, operational procedures, airspace geometry, weather models, and so forth. Some models use current-day jet routes, while others assume that the routing across the airspace can be redesigned to maximize capacity (e.g., parallel flows of traffic across FCAs) or maximize user preferences (Free Flight). The ATM-impact evaluation can be done for different parameterizations (from conservative to aggressive, with a variety of safety margins representing pilot and airline preferences), to evaluate a range of impacts of the weather on the nominal capacity. Modeling errors will result in capacity estimation errors.

En route Convective Weather Avoidance Modeling. An en route Convective Weather Avoidance Model (CWAM) calculates Weather Avoidance Fields (WAFs) as a function of observed and/or forecast weather. WAFs are 2D or 3D grids whose grid points are assigned either a probability of deviation or a binary deviation decision value (0 or 1). CWAM requires both the inference of pilot intent from an analysis of trajectory and weather data and an operational definition of deviation. Two approaches have been taken to model and validate weather-avoiding deviations using trajectory and weather data: trajectory classification and spatial cross-correlation.

Terminal Convective Weather Avoidance Modeling. In order to determine the impacts of convective weather on terminal air traffic operations, CWAM models must be modified to take into account the constraints of terminal area flight to calculate WAFs that apply specifically to terminal area operations. Each WAF grid point is assigned a probability and/or a binary value (0 or 1) that represents that likelihood that pilots will choose to avoid convective weather at a point location in the terminal area. For instance, departures and arrivals are constrained to follow ascending or descending trajectories between the surface and cruise altitude, leaving little flexibility to avoid weather by flying over it. Aircraft flying at low altitudes in the terminal area appear to penetrate weather that en route traffic generally avoids. The willingness of pilots to penetrate severe weather on arrival increases as they approach landing.

Mincut Algorithms to determine Maximum Airspace Capacity. For NextGen when jet routes can be dynamically redefined to adjust flows of traffic around weather constraints, the maximum capacity of an airspace may be determined using extensions of MaxFlow/Mincut Theory. A continuous flow version of the network MaxFlow/Mincut Theorem is suitable for estimating the maximum throughput across an en route airspace given a traffic flow pattern, a uniform distribution of flow monotonically traversing in a standard direction (e.g., East-to-West), or random, Free Flight conditions. Given a required gap size between weather constraints (how big the gap must be to safely fly through it), an algorithm identifies the mincut bottleneck line – this mincut determines the maximum capacity in terms of the maximum number of air lanes that can pass through the gaps in the weather for a specified altitude range. Capacity is determined by analyzing mincut values from the lowest to highest altitude in a sector as a function of time given a weather forecast.

Weather-Impacted Sector Capacity considering CWAM and Flow Structure. NAS sectors typically exhibit a small set of common traffic flow patterns, and different patterns represent different levels of traffic complexity. Quantifying sector capacity as a function of traffic flow pattern provides a basis for capturing weather impact on sector capacity. The future traffic flow pattern in the sector is predicted and described with flows and flow features. The available flow capacity of each flow in the predicted traffic flow pattern is determined by MaxFlow/Mincut Theory applied to a Weather Avoidance Altitude Field (WAAF) – a 3D version of the CWAM WAF. The available flow capacities are combined and translated to the available sector capacity based on the traffic on each flow and the normal sector capacity given the predicted traffic flow pattern.

Route Availability. Several ATM tasks, including departure and arrival flow management and the planning of weather-avoiding reroutes, require the assessment of the availability and/or

capacity of individual traffic routes or flows. Thus, it is natural to extend Maxflow/Mincut, CWAM, and WAF concepts into route availability. A route is available if traffic can follow a route and stay within acceptable deviation limits around the route centerline while avoiding hazardous weather. The route capacity indicates the rate of traffic flow that an available route can support. Estimating route availability may be achieved by Maxflow/Mincut and Route Blockage techniques. Capacity estimates must account for the workload and uncertainty involved in flying the weather-avoiding trajectories that they identify.

Directional Capacity and Directional Demand. Since traffic flow patterns are directional, capacity is also directional. The capacity of an airspace can be estimated for a series of 'cardinal' directions, e.g., North (N), East (E), South (S), West (W) and the diagonals NE, NW, SE, and SW. Also, directions can be quantified every Θ degrees (e.g., Θ=20 deg.), spaced around a given NAS resource, for instance, around an airport, metroplex, or fix location, or within a section of airspace. For each angular wedge of airspace, the maximum capacity for traffic arriving from a specified direction may be established. MaxFlow/Mincut techniques as well as scan line techniques have been demonstrated. The maximum capacity for a particular angular wedge of airspace will quantify the permeability of the weather with respect to traffic arriving from a specified direction. The challenge is to determine acceptable amounts of traffic that may pass through in given directions, subject to controller workload limits.

The Weather Impacted Traffic Index. The Weather Impacted Traffic Index (WITI) measures the number of flights impacted by weather. Each weather constraint is weighted by the number of flights encountering that constraint in order to measure the impact of weather on NAS traffic at a given location. Historically, WITI has focused on en route convective weather, but the approach is now applied to other weather hazard types as well. A WITI-B variation evaluates the extent to which a flight would have to reroute in order to avoid severe weather. The En route WITI (E-WITI) for a flow is the product of its hourly flight frequency and the amount of convective reports in a region of airspace. Another approach apportions all en route WITI measures to origin and destination airports. Terminal WITI (T-WITI) considers terminal area weather, ranked by severity of impact, and weights it by the departures and arrivals at an airport. The National Weather Index (NWX) implements the WITI on a NAS-wide scale.

Weather-Weighted Periodic Auto Regressive Models for Sector Demand Prediction. Traditional air traffic flow prediction models track the aircraft count in a region of the airspace based on the trajectories of proposed flights. Deterministic forecasting of sector demand is routinely done within ETMS, which relies on the computation of each aircraft's entry and exit times at each sector along the flight path. Since the accuracy of these predictions is impacted by departure time and weather uncertainties, and since weather forecast uncertainty causes errors in the sector count predictions, traditional methods can only predict the behavior of NAS for short durations of time – up to 20 minutes or so. It is difficult to make sound strategic ATM decisions with such a short prediction time. An empirical sector prediction model accounts for weather impact on both short-term (15 minutes) and mid-term (30 minutes to 2 hours) predictions. Different from traditional trajectory-based methods, Periodic Auto-Regressive (PAR) models evaluate the performance of various demand prediction models considering both the historical

traffic flows to capture the mid-term trend, and flows in the near past to capture the transient response. A component is embedded in the model to reflect weather impacts on sector demand.

Stochastic Congestion Grids. A stochastic congestion grid quantifies congestion (density of aircraft) in a way that accounts for the uncertainty of the aircraft demand and uncertainty of the weather forecast (convection, turbulence, or icing) for long look-ahead times, as required by strategic TFM planning processes. Each grid cell records an estimate of the probability that the expected traffic exceeds a threshold level. In NextGen, 4D trajectories are stored in the 4D congestion grid by projecting the 4D trajectory onto the grid with an error model for along track error and cross track error. An increase in probability of congestion occurs where the traffic flow increase coincides with a predicted weather constraint. A probability that a weather constraint will exist is described on a grid cell instead of a binary value for a constraint versus no constraint. If the probability that traffic in any 4D grid cell exceeds tolerable thresholds, then appropriate TFM planning is warranted.

Translation of Ensemble Weather Forecasts into Probabilistic ATM Impacts. In NextGen, in order to capture the uncertainties posed by long-term weather forecasting, strategic TFM planning will rely on probabilistic ensemble weather forecast information. Ensemble forecast systems generate a series of deterministic forecasts of potential weather outcomes (i.e., members of the ensemble). Each forecast represents a possible weather scenario that may emerge later in the day. These weather forecasts, in turn, are translated into ATM impacts with relative likelihoods and probability density functions (pdfs) for either use by humans-over-the-loop or computer-to-computer ATM applications. The definition of a weather hazard could be for convection, turbulence, icing, or other aviation-relevant hazards and events (e.g., major wind shifts at an airport), and any appropriate weather hazard model can be placed into the ensemble-translation process; for instance, the CWAM WAF for a given altitude range.

Translation of a Deterministic Weather Forecast into Probabilistic ATM Impacts. NextGen systems can benefit from understanding how a single deterministic forecast in a grid-based format, and some error bounds associated with the forecast, can be used to create probabilistic ATM impacts for airspace regions. Variations on a single deterministic forecast are created by considering error models that account for errors in timing, errors in coverage, translational errors, and echo top errors. A synthetic ensemble of forecasts is created that are similar (perturbations) to the input deterministic forecast. The set of erroneous forecasts represents “what if” cases; “what if the weather system arrives early (late)”, “what if it is larger (smaller) than expected”, etc. The underlying assumption is that the weather organization has been correctly forecasted, but the speed, growth, or decay of weather cells may be in error. The synthetic ensemble of erroneous forecasts is then input into an ATM-impact model, for instance, a Maxflow/Mincut method, route blockage method, or CWAM model, and a set of ATM-impacts is output. This probabilistic estimate may assist users or the ANSP in assessing risks associated with weather impacts.

Sensitivity of NAS-wide ATM Performance to Weather Forecasting Uncertainty. Planners need to understand sensitivity of ATM performance to the weather forecasting uncertainty in order to make research and development decisions. The ATM performance improvement (benefit) is determined by comparing the performance sensitivity and a contemplated forecasting

uncertainty reduction. Simulation is typically required to model ATM performance. Such a simulation must include effects of the weather and its forecast in order to model the sensitivity to the weather forecasting uncertainty. For instance, such effects might include the modeling of vectoring, rerouting and ground hold decision making models in response to weather forecasts. The ATM performance simulations require weather forecasts of varying accuracy in order to evaluate the sensitivity to forecasting uncertainty.

Use of Probabilistic Convective Weather Forecasts to Assess Pilot Deviation Probability. The operational probabilistic weather product called the National Convective Weather Product–6 (NCWP-6) provides up to 6-hour forecasts of the probability of convection. One way to translate probabilities of convective to ATM impact is to determine a correlation between aircraft position and NCWF-6 convective probability values, at the appropriate flight level and relative distance above the echo top. Using the correlation, a decision-maker could assess the NCWF-6 probability that aircraft are willing to traverse, and in turn, the risk associated with traveling in the vicinity of forecasted NCWF-6 probability contours. The Probability Cut-off Parameter (PCP) is the maximum NCWF-6 probability contour which correlates with a majority of aircraft positions based on historical analysis. PCP values differ with forecast times and they can be established for a local scope, at sector and center levels.

Integrated Forecast Quality Assessment with ATM Impacts. In order to better understand the application of convective weather forecasts into the ATM planning process, convective forecast products need to be objectively evaluated at key strategic decision points throughout the day. For example, a sector-based verification approach along ATM strategic planning decision points and a measure of weather impact across the NAS can be used to evaluate convective weather forecast quality in an operational context. The fundamental unit of measure is applied to super high sectors – the volumes that are used for strategic air traffic planning of en route air traffic. The goal is to correctly transform the forecast into sector impacts quantified by the ATM impact model that applies, for instance a directional capacity impact in the direction of flow established by the ATM flow plan. ATM impact models must be tied into the evaluation of weather forecast quality in a way that the ATM impact is accurately predicted in measures that are meaningful to the ATM application.

Conditioning ATM Impact Models into User-relevant Metrics. In order to translate weather forecasts into useful information for ATM planners, weather forecasts need to be calibrated, not with respect to meteorological criteria, but with respect to operational planning criteria. Since the airlines participate in the ATM process through Collaborative Decision Making (CDM) processes, calibrated ATM-impacts must be expressed in meaningful terms to the airlines (dispatch and ATC coordinators) as well as to the ANSP. When planning and scheduling flows of air traffic to cross the NAS, one must project flight schedules and trajectories and weather forecast information into an ATM impact model to arrive at delay estimates (arrival and airborne delays), cancellation estimates, and cost estimates. In NextGen, post-process analysis can be used to adjust the bias on ATM impact models so that future ATM impacts best model actual costs. In NextGen, it will be critical that the impacts of weather information be calibrated with respect to ATM operational decisions for effective planning and automated decision support.

Integration of the Probabilistic Fog Burn Off Forecast into TFM Decision Making. The situation at San Francisco (SFO) International Airport provides an opportunity to explore the integration of probabilistic weather forecasts into TFM decision making. This case involves a forecast of a single weather parameter – the marine stratus (fog) burn off time – at a fixed geographical location (the SFO approach zone). Traffic managers initiate a Ground Delay Program (GDP) to reduce the inflow of aircraft when fog at SFO lingers well into the morning arrival rush, thereby reducing the AAR in half (because only one runway can be used instead of two). One must rate the confidence of each of several forecasts, and use empirical errors of historical forecasts in order to create a probabilistic forecast in terms of a cumulative distribution function of clearing time. To address the ATM impact, a weather translation model must integrate SFO's probabilistic fog burn off forecast in with GDP algorithms.

Mincut Algorithms given Hard/Soft Constraints to determine Maximum Capacity. The Maxflow/Mincut problem assumes that weather hazards are classified in a binary way: traversable or not (hazardous or not). The assumption is that all hazards are hard constraints. However, weather hazards, including the "types" of convection, turbulence, icing, and other weather effects may more generally be classified into hard and soft constraints. Hard constraints are formed by weather hazards that no aircraft can safely fly through (e.g., severe convection, turbulence or in-flight icing). Soft constraints are formed by weather hazards which some pilots or airlines decide to fly through while others do not (e.g., moderate turbulence or icing). Define Class 1 aircraft to be those that avoid both hard and soft constraints, and Class 2 aircraft to be those that avoid hard constraints but are willing to fly through soft constraints. The problem is that of multi-commodity flow, in which the goal is to determine if there exists a set of air lanes, each with an associated Class of aircraft (the "commodity"), such that each air lane satisfies all constraints from the weather types that impact the Class, and such that the air lanes yield a set of flows that satisfy the demand, or some fraction of the demand.

ATM Impact of Turbulence. Unexpected turbulence injures crew and passengers, and potentially can damage aircraft. The hazard results from several different atmospheric phenomena including jet stream interaction, shear, mountain wave generation, and convection. Two distinct types of turbulence are of concern – Clear Air Turbulence (CAT) and Convective Induced Turbulence (CIT). The ATM impact results from pilots desiring to avoid or exit turbulent conditions for safety reasons. This may happen tactically or strategically. Alerting to potential turbulence is important so that the cabin can be properly secured prior to an encounter. Exiting an unplanned encounter requires information to identify an acceptable exit strategy (that is, climb or descend to airspace clear of turbulence, or avoid by changing horizontal flight path to a region clear of turbulence). The exit strategy can be determined tactically, essentially as an aircraft is experiencing turbulence, or is warned that it is about to enter it, or strategically, with sufficient planning time to enter into a region of potential turbulence or avoid it altogether.

Tactical Feedback of Automated Turbulence electronic Pilot Reports. NextGen will likely automate the process of collecting and distributing turbulence (as well as other) PIREP information. Such automated e-PIREPs will automatically and frequently report PIREPs by data link to ATC and to nearby aircraft. With a collection of e-PIREP information reported at a wide variety of flight levels (null as well as hazard reports), turbulence information can be data linked

directly to nearby aircraft or collected and distributed via a centralized database. Thus, hazardous airspace as well as airspace clear of turbulence can be communicated to nearby aircraft that are soon to pass into such airspace. Since turbulence is a transient hazard, this process needs to be automated, a data link needs to quickly communicate information to nearby aircraft, and the process must repeat throughout the day for detecting CIT and CAT hazards.

ATM Impact of Winter Weather at Airports. The accumulation of ice on aircraft prior to take off is a significant safety hazard affecting aircraft. Research indicates that the icing hazard for aircraft directly corresponds to the amount of water in the snow, rather than visibility – the traditional metric used to determine de-icing and take off decisions. Results from field tests of de-icing fluids have identified the liquid-equivalent snowfall rate as the most important factor determining the holdover time (time until a fluid fails to protect against further ice build-up). The ATM impact of decisions made regarding aircraft de-icing holdover times, de-icing fluid types, and application procedures have yet to be defined and integrated into a NextGen gate-to-gate concept of operations.

ATM Impact of In-Flight Icing. In-flight icing impacts air traffic flow in complex ways. For aircraft not certified for icing conditions, all known or forecast icing is prohibited airspace. Some situations have icing severity and aircraft equipage combined to define a “soft” constraint – some properly equipped aircraft may penetrate the icing volume for limited exposure times. In-flight icing is typically a low altitude hazard, generally less than FL200. Major ATM impacts, therefore, are seen for low-end General Aviation (GA) and for all aircraft in the arrival/departure and terminal phases of flight. National ATM impact can be significant when icing affects large airport metroplexes.

ATM Impacts derived from Probabilistic Forecasts for Ceiling and Visibility and Obstructions to Visibility. The Ceiling and Visibility (C&V), and Obstructions to Visibility (OTV) impacts differ depending on the flight regime (terminal, en route, ground operations) and type of aircraft operation. The core forecast technology for OTV, plus translation to ATM impact and decision support dealing with uncertainty, are technology gaps that still need to be addressed for NextGen.

Improved Wind Forecasts to predict Runway Configuration Changes. The airport configuration is a primary factor in various airport characteristics such as arrival and departure capacities (AARs and ADRs) and terminal area traffic patterns. The wind speed and direction is essential in determining which runways are feasible. Terminal Aerodrome Forecasts (TAFs) do not currently predict wind conditions precisely enough or accurately enough to enable airport configuration prediction. NextGen weather forecast systems must correct this in order to assimilate weather into DSTs for airport surface operations as well as TFM decision making. As for modeling the ATM impact, there is also research needed to establish the relationship between how controllers choose between viable configurations to meet the arrival and departure demands of an airport.

Improved Wind Forecasts to facilitate Wake Vortex Decision Support. Knowledge of wake vortex characteristics and behavior in near real time allows the opportunity to safely reduce existing separation standards to increase throughput, particularly within the terminal airspace.

Recent efforts have focused on wind dependent solutions where a very short term wind forecast (20 minutes) is sufficient to determine when persistent transport crosswinds protect specific Closely Spaced Parallel Runways (CSPR) from the threat of a wake vortex moving into the departure flight path, thereby safely allowing reduced separations.

Impact of Winds Aloft on the Compression of Terminal Area Traffic Flows. Generally, when strong winds aloft are present, the wind speed will vary considerably with altitude. This will cause large variations in groundspeeds between aircraft at different altitudes and thus in trail spacing becomes difficult to maintain. From an ATM perspective, currently, larger MIT restrictions are issued to deal with this effect, which controllers refer to as compression. Generally when winds aloft impact the airspace, MIT restrictions have to be increased, and there is also the possibility of impacting performance with a lower AARs with the potential of GDPs and Ground Stops (GS). The outstanding issue is how to translate this information to determine compression effects on ATM, and how the requirements relate to the weather forecast accuracy.

Oceanic/Remote Weather Integration. The NextGen Concept of Operations envisions a seamless transition between CONUS, terminal, and oceanic domains. Weather information for oceanic and remote areas will be integrated with ATM at the same level as for CONUS operations. However, weather information for remote and oceanic regions is more difficult to create than for the CONUS because data is sparse. This requires creative use of available data from satellites and other limited sources, and is an area of active research. Prototype algorithms have been developed for regional use, but not integrated with ATM procedures. For instance, studies demonstrate how wind data can be used to generate wind optimal routes, transitioning away from the fixed oceanic routes to user-preferred routes. While such routing takes advantage of the jet stream, it also must take into account turbulence that can be found near the jet stream, which is an area of future research.

Translation of Volcanic Ash Plume Hazards onto ATM Impacts. Advanced techniques are needed in NextGen that will detect, forecast, and disseminate information on volcanic ash plume hazards and how the hazards will affect ATM resources to aviation operators and users. Airborne volcanic ash constitutes a recognized threat to aviation that can severely damage jet aircraft engines through erosion, corrosion, and congestion. Volcanic ash contamination may render large volumes of airspace unavailable, necessitating costly rerouting contingencies, degrades braking action at affected airports, as well as completely closes contaminated airports. The weather translation model for volcanic ash plume hazards requires further advancement of both science and operational modeling.

Translation of Atmospheric Effects into Environmental and ATM Impacts. Environmental impacts will be significant constraints on the capacity and flexibility of NextGen. The major environmental effects include emissions of pollutants, greenhouse gases, aircraft noise, and water pollution via de-icing agents, spilled fuel, etc. Most environmental impacts are affected by the atmosphere and will require the integration of probabilistic weather forecast elements for proper risk management. Weather affects the strength and direction of acoustic propagation, dispersion of mixing of air pollutants, and effects on engine performance and fuel usage. Environmental impacts are translated into ATM impacts via several mechanisms, including: Mitigation measures such as specialized departure and arrival procedures and routings, as well as restricted

periods of operation; Routing and altitude assignments that seek to minimize fuel consumption (and possibly contrail formation); and Surface and system management that seeks to minimize taxi times and delays on the ground with engines running.

ATM Impact of Space Weather. There is a growing threat from space weather as aviation's dependence on space and terrestrial networks vulnerable to solar weather continues to grow. The threat also exists for communication and navigation services for long-haul polar flights. Even relatively minor solar storms can affect these services and cause flights to reroute, divert, or not even dispatch over polar regions. Thus, an increase in polar flight activity in NextGen will bring about an increase in NAS delays from space weather impacts during times of high solar activity. We can expect an as-yet undefined impact to the net-centric NextGen infrastructure in the CONUS as well. Moreover, the human exposure to space radiation is significantly higher on polar routes, which poses a potential health risk.

ATM Impact of Weather Constraints on General Aviation. While the number of studies that have been performed to build ATM impact translation models has been increasing over the years, few and possibly none of these have focused on the particular parameters that model GA aircraft in particular, or have quantified the overall impacts to GA pilots in the aggregate.

4.2 Maturity and Gap Analysis

This section is to assess the maturity of the ATM-impact models presented, and to identify gaps in technologies that must be addressed for NextGen. In order to assess the maturity of each ATM-impact model, we use the following criteria:

- Low Maturity – The concept is defined, however, there is no theoretical foundation or scientific data gathered to build the mathematical model for the concept
- Medium Maturity – The concept is defined and a theoretical foundation or scientific data is gathered for a mathematical model for the concept
- High Maturity – The concept is defined, a mathematical model is established, and effort has been made to verify and refine the model for acceptable operational use, and
- Full Maturity – The concept is an acceptable method of modeling ATM-impact and is in operational use.

Note that no ATM-impact model that has been reviewed is at full maturity. For instance, there is no established and accepted indicator of airspace capacity in the NAS today. Most of the ATM-impact models fall in the low and medium maturity levels, with further research, development, and deployment needed. Table 4-1 provides an assessment of the maturity of the ATM-impact models described in this survey.

Table 4-1. Level of Maturity for ATM-impact Models.

ATM-impact Model	Low	Medium	High	Full
CWAM for En Route Airspace			**x**	

Table 4-1. Level of Maturity for ATM-impact Models.

ATM-impact Model	Low	Medium	High	Full
CWAM for Terminal Airspace		x		
CWAM with Flow Structures		x		
Maxflow/Mincut Methods for Convection		x		
Route Availability Methods			x	
Directional Capacity Methods		x		
WITI Metric Models		x		
Periodic Auto Regressive (PAR) Models		x		
Stochastic Congestion Grids		x		
Ensemble Forecasts translated into Probabilistic ATM impacts		x		
Deterministic Forecasts translated into Probabilistic ATM impacts		x		
Sensitivity of ATM Performance to Weather Forecast Uncertainty		x		
Probabilistic Convective Forecasts and Pilot Deviation Models		x		
Integrated Forecast Quality Metrics in ATM-impact Models		x		
Conditioning ATM-impact models for User relevant Metrics		x		
Probabilistic Fog-Burnoff Modeling for AAR Planning			x	
Maxflow/Mincut Methods for Hard/Soft Constraints		x		
Tactical e-PIREP Feedback		x		
ATM-impact Models for Turbulence		x		
ATM-impact Models for In-flight Icing		x		
ATM-impact Models for Winter Weather at Airports		x		
ATM-impact Models for C&V and OTV	x			
Improved Wind Forecasts to Predict Runway Configuration Changes	x			
Improved Tactical Wind Forecasts for Wake Vortex Mitigation			x	
ATM-impact Models for Oceanic/Remote Weather	x			
ATM-impact Models for Volcanic Ash	x			

Table 4-1. Level of Maturity for ATM-impact Models.

ATM-impact Model	Low	Medium	High	Full
ATM-impact Models for Space Weather	**x**			
ATM-impact Models based on Environmental Factors	**x**			
ATM-impact Models affecting GA	**x**			

Gaps in ATM-impact modeling include the following:

- Human Factors (see C-5, including Human-in-the-Loop (HITL) Simulations, Roles and Responsibilities, and Culture, need be included into ATM-impact models to adequately address capacity limitations that are driven by controller, dispatcher, and pilot workload, complexity, displays, collaboration and team work between various decision makers, etc.
- The role of Collaborative Decision Making (CDM) and how it influences the demand on a weather-impacted resource, enforcement of company policy, and the coordination and collaboration of TFM solutions needs to be integrated in with future ATM integration solutions.
- Any model that observes how pilots fly in today's NAS does not represent how pilots may fly in NextGen when new technology and new procedures are likely to be in place. There is a need to transform a lot of ATM-impact models into NextGen conditions. However, it is difficult to validate such models, except in simulation environments. Similarly, as various air traffic automation tools to assist in separation of aircraft from other aircraft are introduced, it will be necessary to recalibrate the models that translate weather impacts into capacity impacts. Here again, simulations may be needed.
- Work is also required to determine how to properly combine impacts from multiple ATM-impact models to evaluate the magnitude of expected ATM impact from multiple weather types. For example a segment of airspace may be simultaneously experiencing impacts from convection, elevated haze, turbulence and volcanic ash. The impact of each environmental condition may be calculated (deterministically or stochastically) by individual impact models; yet rolling them up into an integrated impact will not likely be commutative since each of these events are not likely statistically independent. Complicating the task of integrating these various impact models into one is the fact that each model reviewed in this section is at a different level of maturity, as indicated in Table 4-1.
- 4D hazard information needs to be integrated with winds and temperature effects on all flight profiles. Airline dispatchers and pilots using 4D flight planning systems can then strategically plan flight profiles and, most importantly, pilots can prepare to react tactically to real-time hazard information prior to an encounter with any aviation weather hazard.

- This discussion on gap analysis is at a very high level because that is work that needs to be done. Performing a gap analysis is part of the foundation building called for in paragraph 5.1.1, performed by the team identified in paragraph 5.2.2.2 and under the oversight of the board identified in paragraph 5.2.3

4.3 Survey of ATM-Weather Integration Technologies

Many of the ATM-impact models will eventually be integrated into DSTs in order to help users reason about the impacts of weather while solving ATM problems. The survey includes approaches for addressing weather-related uncertainty in ATM decision making for strategic look ahead times – risk management processes – as well as approaches that wait until the tactical look ahead times to address deterministic forecasts after the uncertainties diminish. The ATM-weather integration techniques make reference to ATM-impact models as appropriate. An assessment of maturity of these ATM-weather integration technologies and a gap analysis are given at the end of the section.

Sequential, Probabilistic Congestion Management for addressing Weather Impacts. Flexibility and adaptability in the presence of severe weather is an essential NextGen characteristic. Sequential, probabilistic congestion management describes how to incrementally manage en route airspace congestion in the presence of uncertainties. Sequential, probabilistic congestion management can take advantage of probabilistic weather forecasts to reduce weather impact on en route airspace. It would also provide an effective “inner loop” to be used in conjunction with strategic flow management initiatives, based on longer-range weather forecasts. Note that an alternate, multiple-timescale sequential congestion management approach has also been proposed. This method does not employ probabilistic forecasts, but rather relies on adapting to observed weather development.

Sequential Traffic Flow Optimization with Tactical Flight Control Heuristics. A deterministic sequential optimization approach integrates a strategic departure control model with a fast-time simulation environment to reactively control flights subject to system uncertainties, such as imperfect weather and flight intent information. To reduce the computational complexity of the strategic model, only departure delays are assigned, while tactical en route flight control is accomplished through heuristic techniques.

Airspace Flow Programs to address 4D Probabilistic Weather Constraints. An Airspace Flow Program (AFP) is a particular type of Traffic Management Initiative (TMI) that controls traffic flowing into an airspace where demand is predicted to exceed capacity. A FCA is defined to be the boundary of the region of airspace where demand exceeds capacity – most typically, due to convective weather constraints. Today’s AFPs use fixed locations for FCA boundaries used for AFPs, and these regions are defined by air traffic control center and sector boundaries, not the location of the weather constraint itself. In NextGen, the FCA is likely to be a 4D volume that describes the space-time region where weather constraints (not only convection, but severe turbulence and icing regions as well) cause significant ATM impacts. Because the AFP must reason about the effects of weather on airspace capacity for long lookahead times, it is necessary for the AFP to reason about a probabilistic estimate of capacity.

Ground Delay Program Planning under Capacity Uncertainty. Uncertainty in capacity forecasts poses significant challenge in planning and controlling a GDP. There are two main decisions associated with any GDP: (1) setting the AAR, and (2) allocating landing slots to flights, and hence, to the airlines who operate those flights. Static and dynamic stochastic optimization models are appropriate for NextGen.

Contingency Planning with Ensemble Weather Forecasts and Probabalistic Decision Trees. Management of the complex interaction between potential weather outcomes and TMIs can be modeled using a collection of potential weather scenarios. These would be retained in an ensemble forecast, which would serve as input to a Probabilistic Decision Tree. Flow planners would make use of this to form a primary plan and contingency flow plans (one for each possible weather scenario) (for instance, strategic two to four hours in the future). This assists in the strategic planning of GDPs, AFPs across FCAs as well as tactical GSs, holding, metering, reroutes, and other plans.

Probabilistic Traffic Flow Management. The strategic TFM problem is inherently stochastic since both the traffic loadings and system capacities are difficult to forecast precisely over such long time horizons. Strategic TFM solutions need to account for forecasting uncertainties, forecasted traffic loadings, and estimated system capacities. The specific solution method can take several forms. One is a resource allocation solution involving a combination of rerouting and ground delay. This probabilistic TFM concept has a high maturity level, as it has been defined, analyzed and verified at various levels.

A Heuristic Search for Resolution Actions in Response to Weather Impacts. Uncertainties present in demand, weather, and capacity, create a need to resolve congestion in an efficient and flexible manner. In both the strategic and tactical time frames, the methods utilized to resolve congestion should provide metrics to measure the quality of the proposed solutions. A Generalized Random Adaptive Search Procedure (GRASP) can address this problem through a computationally-efficient heuristic optimization approach. GRASP finds feasible solutions quickly and evaluates proposed solutions against defined metrics to determine the set of resolution maneuvers that best satisfies the objectives.

Integrated Departure Route Planning with Weather Constraints. NextGen will require an Integrated Departure Route Planning (IDRP) capability in order to handle departure traffic efficiently and safely. The IDRP capability must integrate departure route and en route sector congestion information, especially when weather constraints are present and traffic demand must dynamically adjust to predicted downstream capacity fluctuations. This concept also applies to downstream weather constraints such as convection, turbulence, or icing. The IDRP capability reduces the time needed to coordinate and implement TMIs and supporting departure management plans.

Tactical Flow-based Rerouting. This concept for rerouting air traffic flows around severe weather is for a tactical timeframe (0 to 2 hours out) and requires an ATM-impact model for route blockage. In this timeframe, weather predictions are relatively good, so the reroutes can be closer to the weather than strategic reroutes and thread through smaller gaps between weather cells. Automated solutions makes tactical rerouting easier, increasing the ability of traffic

managers to implement them. Moving this activity from controllers to traffic managers will reduce controller workload, thereby safely increasing airspace capacity during severe weather.

T**actical On-Demand Coded Departure Routes.** This concept for rerouting air traffic flows around severe weather is based on moving today's static, fixed Coded Departure Route (CDR) framework for rerouting traffic on jet routes during severe weather events into a dynamically defined "On Demand" CDR framework for NextGen for routing 4D trajectories in a tactical timeframe (0 to 2 hours out). An ATM-impact model is needed to identify route blockage ahead of time as well as the ability to design space-time reroutes between city pairs with a 1-2 hour look ahead time. The purpose of On-Demand CDRs is to move the rerouting decision as close to the tactical time horizon as possible to eliminate the uncertainty in rerouting – eliminating the potential for several weather outcomes, as is the case in ensemble weather forecasts, and focusing in on one projected weather outcome in the tactical time frame.

4.4 Maturity and Gap Analysis

This section is to assess the maturity of the ATM-weather integration technologies, and to identify gaps in technologies that must be addressed for NextGen. In order to assess the maturity of each ATM-weather integration technology, we use the following criteria:

- Low Maturity – The concept is defined (e.g., in the form of an operational concept), however, there is no theoretical foundation or scientific data gathered to explore the ATM-impact models and performance of the ATM-weather integration technology.
- Medium Maturity – The concept is defined and a theoretical foundation and/or scientific data is gathered for a mathematical model for ATM-impact components, components of the technology have been assembled in a prototype system, and some evaluation of performance has been demonstrated.
- High Maturity – The concept is defined, a models have been established, and effort has been made to verify and refine the models and prepare the technology for acceptable operational use, and
- Full Maturity – The integrated technology is an acceptable technology in operational use integrating an ATM-impact model with a deployed DST in the NAS.

Note that no ATM-integration technology that has been reviewed is at full maturity. For instance, just as there is no established and accepted indicator of airspace capacity in the NAS today, there is also no indicated airspace capacity ATM-model imbedded into any DST in use in the NAS. Most of the ATM-impact models fall in the low and medium maturity levels, with further research, development, and deployment needed. Table 2 provides an assessment of the maturity of the ATM-weather integration technologies described in this survey.

Table 4-2. Level of Maturity for ATM-Weather Integration Technologies

ATM-Weather Integration Technology	Low	Medium	High	Full
Sequential Probabilistic Congestion Management		x		
Sequential TFM with Tactical Flight Control		x		

Table 4-2. Level of Maturity for ATM-Weather Integration Technologies

ATM-Weather Integration Technology	Low	Medium	High	Full
AFPs with 4D Probabilistic Weather Constraints	x			
GDPs with Capacity Uncertainty		x		
Contingency planning with Probabilistic Decision Trees		x		
Probabilistic TFM		x		
Heuristic Search for Resolution Actions		x		
Integrated Departure Route Planning		x		
Tactical Flow-based Rerouting		x		
Tactical On-Demand CDRs		x		

Gaps in ATM-weather integration technologies include the following:

- As was the case in ATM-impact models, human factors (see C-5) work seems to be missing in a lot of the ATM-weather integration technologies.
- Many of the ATM-weather integration technologies are tied to how pilots may fly in the NAS today, using jet routes, current day sector definitions, and current day traffic demand loads. In NextGen when new technology and new procedures are likely to be in place, and when new concepts allow for more flexible routing strategies (no longer tied to Navaids and jet routes), some technologies may have to change to address such conditions. There is a need to transform ATM-impact models into NextGen conditions, and a need to transform ATM-weather integration technologies to NextGen conditions.
- Work is required for NextGen to determine how to combine impacts from multiple ATM-impact models to ensure the DSTs receive proper magnitude of expected ATM impact from multiple weather types. Not only may an airspace be simultaneously experiencing multiple types of weather impacts, the effects from these impacts in one part of the NAS may affect ATM in other parts of the NAS with upstream and downstream propagation. The ATM-integration effort should not be limited in spatial or temporal scope nor or in the breadth of weather phenomena.
- This discussion on gap analysis is at a very high level because that is work that needs to be done. Performing a gap analysis is part of the foundation building called for in paragraph 5.1.1, performed by the team identified in paragraph 5.2.2.2 and under the oversight of the board identified in paragraph 5.2.3

5 WEATHER INTEGRATION PLAN EXECUTION

The purpose of this section of the plan is to describe first, how the plan will be executed, second, organizational issues and the Weather Integration Methodologies Management Team, and third, the relationship between weather integration, ATM tool developers and the major Aviation Weather Office programs: Reduce Weather Impact (RWI), NextGen Network Enabled Weather (NNEW), Weather Technology in the Cockpit (WTIC), and Aviation Weather Research Program (AWRP).

5.1 Plan Execution

The execution of this plan will occur in four steps. The steps will be executed more or less in sequential order from the start for any given ATM tool, but as will become evident, the steps will be repeated many times as new weather techniques and ATM tools are developed and may be occurring simultaneously at some point in the future. Note that the term “tool” may refer to an automation system for decision support or to a human decision process. The execution steps are:

First, to align teams with each solution set and analyze weather integration requirements for a service and performance-based approach for weather integration as associated with operational relevance. This step will require a mix of operations, programmatic, and meteorological personnel.

Second, to identify the specific weather integration need and insertion points, including performance criteria and value, into ATM tool or decision platform functionality. This step will be highly dependent upon collaboration with the ATM user community and decision tool developers. This step will require a mix of system engineering, tool/design, operations, and meteorological personnel.

Third, to identify and recommend the specific weather integration techniques and technologies that best fit the requirements of a particular TFM tool under development and particularly the insertion points identified in the previous step. This step will require a combination of meteorological, system engineering, and programmatic personnel.

Fourth, to serve as the SME for the ATM Tool development team to assist in interpretation and integration of the weather impacts and methodologies and to evaluate test results. This step will require meteorological and system engineering personnel.

Prior to proceeding with full-scale integration, it is essential that the weather community develop the foundation of data, products and methodologies that will make integration possible.

5.1.1 Foundation for Integration

In order for weather integration to be successful, a robust set of Weather Methodologies must be available. The Methodologies may deal with the translation of weather into impacts or may center more on decision processes, such as dealing with uncertainty in weather forecasts. Appendix B to this plan shows the Methodology set. Members of the set are at varying levels of maturity. Before they are ready for implementation, they will be winnowed down to the most applicable methodologies, brought to a high level of maturity, prototyped in a generic application, and classified according to their proper use and their Technology Readiness Level.

The following will be accomplished in establishing the foundation for integration:

- Conduct preliminary selection of the most promising methodologies based on potential skill, applicability to NextGen needs, cost, and schedule
- Continue engineering development of selected methodologies
- Establish and apply a testbed
- Perform Technology Readiness Level (TRL) assessments of selected methodologies
- Characterize appropriate applications for each selected methodology
- Perform gap analysis to identify un-met user needs
- Demonstrate the methodologies with sample NextGen applications
- Establish a network service for generating multiple-use translated products and supplying them to user systems
- For unique applications, provide user systems with documentation

5.1.2 Integration Process

The following sections describe the four steps for weather integration. These steps are executed sequentially; however, while later steps are being executed, the process can be started at step 1 when new tools or methodologies are developed that support additional integration possibilities.

5.1.2.1 Step 1: Team Alignment and Analysis

There will be teams aligned with the six non-weather Solution Sets: Initiate Trajectory-Based Operation (TBO), Improve Collaborative Air Traffic Management (CATM), Increase Flexibility in the Terminal Environment (FlexTerm), Increase Arrivals/Departures at High Density Airports (HiDensity), Increase Safety, Security, and Environmental Performance (SSE), and Transform Facilities (Facilities). Some teams may support more than one Solution Set. Using the identified assumptions and determination for weather integration for decision support in section 5, each team is to identify the set of operational tools, processes and initiatives which will support their solution set capabilities.

The team is to be comprised of a broad cross-section of operational users, planners, and engineers, who are intimately familiar with the use and relative value of each identified tool. Additional team members include those who can describe Near-Term functional migration of these tools (operational functions) and who could verify/validate further functional migration into Mid-Term and Far-Term timeframes. If there is no migration path, then team members must be capable of joining with the Solution Set Coordinators in making appropriate assumptions in regard to what tools and what functions will support the capabilities.

There is a need for team members who can identify, either through previous documentation or perception, which of the entire operational tool list qualifies as a potential candidate for weather integration need. This will be a subset of the entire tool set.

The team is to contain operational users that can describe various levels of real or perceived tool improvement (first based on current operational practices and use and then via assumptions on how functionality from tool migration may work). Many tools for the mid-term and far-term do not yet exist, and the team is to apply their judgment in combination with that of the tool creators andowners. By understanding the kinds of output changes a tool must demonstrate for value to be perceived, the relative value of weather, including the relative success of the integration, can be more easily measured against tool improved value from the perspective of the end user.

The meteorological team members would verify/validate the assumptions used in Section 3 and Appendix A of this plan for the need for and use of weather. They would also validate the methodology described there. Programmatic team members would verify migration and/or functionality evolution plan within the enterprise architecture, office coordination and funding.

Information developed in Step 1 will be documented as an update to Appendix A of this plan.

Step 1 Exit Criteria: Step 1 has been completed when the weather team has identified decision functionality that requires integrated weather and has developed a framework or roadmap for moving forward toward user capabilities. This includes the human resources required to complete the integration process.

5.1.2.2 Step 2: Weather Integration Insertion Determination

Step 2 addresses user needs and tool requirements for weather integration and specifically where weather integration should focus (i.e., weather insertion points within the tools or processes as identified in Step 1).

Together with the user tool developers, during this step the weather integration team members consider the decision processes and tool functionality that would be affected when weather occurs. For example:

The presence of convective weather would reduce the capacity of a route and alter use of that route; that would be noted as a weather impact point.

Ceiling and visibility conditions may determine whether an airport should be operating under IFR or VFR, thereby impacting airport capacity.

Cross winds and turbulence paired with lateral runway separation may determine impact the decision of whether an airport should run dependant or independent runway operations.

Space weather introducing errors into GPS position information may impact the landing categories.

The weather phenomena will be prioritized according to the severity and likelihood of occurrence of their impacts (exactly how to perform this prioritization is a topic for future research). If it is not practical to address all possible weather impacts, the prioritization will be a basis for choosing among them.

The combined team will consider the time scale of the impact and whether probabilistic information can be applied as a risk management technique. On very short time scales, especially with regard to an individual flight, the single best deterministic weather impact

information may be called for. For strategic decisions over a multi-hour period or when a number of aircraft may be affected, a probabilistic forecast is usually the appropriate way to deal with uncertainty.

This analysis identifies (with assumptions) where weather needs to be integrated into tools and processes that can affect decisions, the types of weather information needed, and may provide a preliminary indication of the performance requirements for the weather impact information. Weather informational gaps can be identified (weather information available today vs. what is needed) to satisfy the need for weather integration within each application at the identified insertion points.

Information developed in Step 2 will be documented as an update to Appendix A of this plan.

Step 2 Exit Criteria: Step 2 has been completed when there has been a decomposition of a decision tool or process to determine the weather integration insertion points and the weather impacts and their characteristics have been identified and prioritized.

5.1.2.3 Step 3: Identification of Specific Weather Techniques

Step 3 is the crucial intersection of user needs and weather impact support. The weather team will support users in considering the decision, tool, and process characteristics from Step 2 and compare those to available weather translation and decision methodologies documented in Appendix B of this plan to identify the best concept to apply. It is incumbent upon the weather community to supply needed weather information. In this step, performance needs (e.g. resolution in time and space of the weather information) will be determined and related to the weather provider teams.

This step will be taken in close cooperation with the ATM tool owners, who have the overall say as to what goes into their tool. It will also be done after coordination with the weather team leadership.

A key technique for making the methodology selection is the use of a demonstration or prototype. Weather methodologies can be demonstrated in a generic sense as a means of showing their benefits and application possibilities. If needed, the ATM tool owners together with weather team members can view the methodology in prototype action in an Integration Laboratory. This will help them to envision how the methodology would be applicable to their own ATM tool.

“Intersections” are a consideration when choosing a methodology. In this use, “intersections” refers to decisions with more than one tool involved or even more than one solution set. The weather team representatives must coordinate with their counterparts on related decision tool teams to ensure that the concept is consistent with team doctrine and a collaborative and coherent NAS.

In the text of this plan, weather methodologies and user capabilities were kept separate in order to facilitate the use of any given methodology with multiple user capabilities. In actual practice, during Step 3, the two may overlap. Tailoring of a methodology to the needs of a particular user capability can occur. What’s more, a developmental effort can occur in which user capabilities

and weather methodologies can be matured together. What's more, the developments can cross over lines between tools, solution sets, near-mid-far-term, strategic versus tactical, and agency roles. Flexibility, focus, discipline, and creativity will all be hallmarks of successful integration.

Key decisions in the process are which specific weather impact parameters are needed for decision support and whether the impacts could be taken from a common use network service or are sufficiently unique that the translation should occur within the ATM tool itself.

Information developed in Step 3 will be documented as an update to Appendix A of this plan and also to Appendix B if applicable.

Step 3 Exit Criteria: Step 3 has been completed when a weather integration methodology has been developed by the tool owners with the assistance of the weather team representative.

5.1.2.4 Step 4: Integration of Weather Technology into TFM Tool

Step 4 takes the selections made in Step 3 and turns them into reality in the context of an ATM tool or decision process. The weather team representative continues to work with the tool owners, providing advice, interpretation, and assistance throughout the development cycle. This extends even into the development of user training.

Information developed in Step 4 will be documented as an update to Appendix A of this plan. Roadmaps and other baseline documents will also be updated if that has not already occurred.

Step 4 Exit Criteria: Step 4 has been completed when the ATM tool or decision process has successfully reached a mature state and has been accepted for use by the user community.

5.2 Organization

5.2.1 Weather Leadership Team

The Weather Leadership Team is the senior management level for weather integration into ATM operations. It consists of the weather integration manager, the FAA Reduce Weather Impact Solution Set Coordinator, representatives from other stakeholder agencies (NASA, DOD, and NOAA), representatives from implementing organizations (such as Systems Operations, Technical Operations, Terminal Services, En Route and Oceanic Service), the leaders of all sub-teams, and others as needed.

The Weather Leadership Team has the following functions and responsibilities

- Carrying out the tasks in the Integration Plan
- Track TRL of target programs
- Provide basis for business decisions, including benefits, cost, risk, schedule
- Track and project Integration level (1 to 4) for target programs, with benefits being derived from each level increase
- Manage the various integration laboratory activities and infrastructure for testing and prototyping and objective inputs to the Weather Integration Technology Evaluation Board on TRL levels

- Track progress
- Make commitments on progress

5.2.2 Weather Integration Sub-Teams

Weather integration sub-teams will carry out the actual work of the integration effort by working with inside ATM program offices to provide support and to suggest weather integration solutions to implementing programs. They will be comprised of systems engineers with an operations background/understanding, programmatic personnel, and meteorologists. The team will execute the steps described in section 5.1.

5.2.2.1 Weather Integration Customer Team.

The Weather Integration Customer Team is predominately a team of operations personnel and ATM Tool developers with knowledge and training in tool operation and weather methodologies. This team will interface directly with members of the target ATM tool and process owners and developers. They will be the weather team representatives whose work is described in Steps 1 through 4 of Section 5.1 of this plan. They will serve as subject matter experts, assisting tool development experts in the best methodologies for insertion of weather into ATM tools.

Members of the Weather Integration Customer Team will be trained on all current weather integration methodologies, ATM operations, NextGen plans and priorities.

5.2.2.2 Weather Integration Techniques Team.

The Weather Integration Techniques Team: is composed of FAA, NASA, NOAA, and DOD representatives with knowledge of weather integration research and ATM decision processes. This team's work is described in Section 5.1 of this plan. This sub-team will conduct weather integration laboratory activities. Roles include:

- Estimate the time needed to advance to the next TRL
- Track and manage methodology developments
- Document what problems are being solved by each developer
- Give users (e.g. DST developers) insight into technologies
- Recommend developmental priorities
- Recommend developmental funding
- Establish and maintain a prototype and demonstration capability for use in refining weather methodologies and in conjunction with users, for assessing and choosing methodologies for a specific integration opportunity.

5.2.2.3 Weather Integration Program Team.

The Weather Integration Program Team will support programmatic elements of the integration effort, including budget, schedule, benefits assessments, and other tasks needed by the integration manager.

5.2.3 Weather Integration Technology Evaluation Board

The role of the Weather Integration Technology Evaluation Board is to provide objective evaluation and grading of the methodologies presented by the Weather Integration Techniques Team. Specifically they will:

- Oversee development of methodologies
- Evaluate and assign TRLs
- Recommend developmental priorities
- State deliverables for each developmental project and evaluate their completion
- Bring focus, discipline, and creativity to the methodology engineering process
- Sponsor development of new weather methodologies to meet needs expressed by the ATM community for which current methodologies do not meet the need on a resolution, accuracy, or timeliness basis.
- Partner with a "Strategic Planning Advisory Review Cadre" (SPARC) to help with TRL assessments.

5.3 Cost, Benefits, and Schedule

Anticipated initial activities

FY10:

- Building weather translation and decision foundation, including test and evaluation capability.
- Stand up Weather Leadership Team and Integration Sub-Teams.
- Identify initial set of DSTs that have the potential for successful weather integration by NextGen IOC. Identify candidate methodologies, brief users, and develop demonstrations of weather methodologies that will yield success.

FY11:

- Conduct successful demonstrations of weather products or methodologies that have the necessary maturity level for integration

FY12:

- Work with user community and DST developers to integrate weather products and methodologies into DSTs for IOC implementation

Detailed weather integration Cost, Benefits, and Schedule information is available in Appendix C.

5.4 Relationship of Integration with Aviation Weather Programs

DSTs essentially remain outside the purview of aviation weather. While weather information drawn from the 4-D Wx SAS must be consistent—i.e., the same published forecast value for a given time and place—the uses to which that information can be put is potentially limitless. The weather may be the same, but its impact is highly variable. The Aviation Weather Office (AWO) communicates with the weather data user community ensuring that the 4-D4-D Wx Data Cube and especially the 4-D Wx SAS contains current and forecast weather data in the form and at the temporal and spatial resolution required to meet all user requirements.

The AWO operates four key programs which play a critical role in the integration of weather into DSTs.

Aviation Weather Research Program (AWRP): The program develops new technologies to provide weather observations, warnings, and forecasts that are accurate, accessible, and efficient. It works to enable flight deck weather information technologies that allow pilots and aircrews to engage in shared situational awareness and shared responsibilities with controllers, dispatchers, Flight Service Station specialists, and others, pertaining to safe and efficient preflight, en route, and post flight aviation safety decisions involving weather. As the Integration effort works with NextGen decision process designers, it will uncover more information about specific user weather requirements. AWRP is addressing those requirements which were identified in preliminary analyses. If additional weather capabilities are identified through the Integration process as new or refined requirements, they will be forwarded through RWI for AWRP to address.

Reduce Weather Impact (RWI): RWI is the primary funding and implementation program for Integration activities. It addresses the need to enable better weather decision making and use of weather information in the transformed NAS. User requirements for weather observations and forecasts identified by the Integration process will be relayed to RWI to ensure that the weather infrastructure can support them. RWI addresses providing improved forecasts and observations, and providing weather forecast information tailored for integration into traffic management decision support systems. RWI will conduct planning, prototyping, demonstrations, engineering evaluation and investment readiness activities leading to an implementation of operational capabilities throughout NextGen near, mid and far terms.

Weather Technology in the Cockpit (WTIC): The Weather Technology in the Cockpit (WTIC) is a research and development program which seeks to ensure the adoption of cockpit, ground, and communication technologies, practices, and procedures that will:

- Provide pilots with shared and consistent weather information to enhance common situational awareness
- Provide airborne tools to exploit the common weather picture

- Utilize the "aircraft as a node", functions to autonomously exchange weather information with surrounding aircraft and ground systems
- Facilitate integration of weather information into cockpit NextGen capabilities (e.g. Trajectory Based Operations)
- Result from WTIC R&D supporting certification and operational approvals.

WTIC is essentially an Integration effort--one dimension of the overall Integration Plan. WTIC efforts will be applied to cockpit weather integration.

NextGen Network Enabled Weather (NNEW): The NextGen Network Enabled Weather (NNEW) develops the standards necessary to support universal user access to needed weather information. It enables the seamless access to standard weather data sets by all NextGen users by establishing the 4-D Wx Data Cube. There will be demonstration efforts to resolve key technical questions and reduce implementation risk of a network-enabled weather environment to the FAA and external system users. This will include assurance that NNEW is fully compatible and consistent with the evolved System-Wide Information Management (SWIM) infrastructure. This will also serve to define open standards and requirements necessary for overall NextGen weather dissemination compatibility. NNEW is the delivery mechanism by which weather information will be provided from weather sources to decision makers. The Integration Team will ensure that the user systems are informed about applicable network-centric standards so that they can obtain and apply the weather information from NNEW capabilities.

The AWRP will fill the technology gap when observing and forecast techniques are not sufficient either in time/space resolution or quality to enable TFM DSTs to have the weather information required to make automated decisions. The RWI program provides a programmatic platform for the AWO to test prototype applications of weather techniques in order to demonstrate that they offer the accuracy and quality for direct application into DSTs. NNEW will provide the means for direct access by DSTs to appropriate weather data.

The key interaction for success in weather integration will be the relationships established between the AWO and the ATM tool development community. The AWO role is to ensure proper use and application of weather data and techniques in development of specific DSTs. During development, the AWO will fund demonstrations for specific technologies in order to demonstrate both the quality and usability of weather information in the decision process. As DST development proceeds, weather data for specific DSTs will transition from a testing scenario to inclusion of production data directly from the 4D Wx Data Cube.

6 ALIGNING THE WEATHER INTEGRATION PLAN WITH PREVIOUS FINDINGS AND RECOMMENDATIONS

There is a need for a multi-agency, synchronized plan to achieve solutions to the problem of weather integration into ATM operations and decisions. As articulated in the NextGen vision, the solution must enable decision makers to identify areas where and when aircraft can fly safely

with weather assimilated into the decision making process in order to optimize the entire national airspace system. The NextGen Weather Integration Plan provides the initial requirements, scope and implementation roadmap to achieve the NextGen vision. It also addresses agency roles and responsibilities and includes resource requirements.

6.1 Weather – ATM Integration Working Group (WAIWG) of the National Airspace System Operations Subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC)

The Weather – ATM Integration Working Group (WAIWG) of the National Airspace System Operations Subcommittee of the FAA's Research, Engineering and Development Advisory Committee (REDAC) conducted a twelve-month study to examine the potential benefits of integrating weather and air traffic management.

The group, with members from airlines, general aviation, NASA, the National Weather Service, national research centers and academia, gathered information during visits to airline operations centers terminals and en route air traffic facilities and research centers. The following key findings and recommendation were reported back to the FAA:

- Few instances of integrated tools exist: time-of-flight estimates incorporating winds aloft; storm free departure times at one airport, and winter deicing timing. All other NAS decision tools use weather manually, as traffic display overlays or on separate displays.
- Aviation weather forecasts have much more accuracy in 0-2 hour, tactical time frame, than the 2-10 hour, strategic time frame. However, the size and shape of the 0-2 hour solution space is much smaller and with increasing congestion, more decisions will have to be made in the latter. Conversely the more the tactical solution space can be expanded, the more decisions can be delayed adaptively and traffic optimized to meet business objectives.
- A risk management approach with adaptive, incremental decision making, based on automatically translating weather forecasts into air traffic impacts, presents a major new opportunity for reducing weather related delays in the future NAS.
- The key recommendation is that a cross cutting research program, involving public and private sector air traffic management and aviation weather experts, is needed to exploit these key findings.

6.2 NextGen Conference on Integrating Weather, Airports, and Air Navigation Services

Over 200 aviation professionals – user, agency and industry stakeholders – converged on Washington, DC for two days in February 2008 to discuss the challenges of meeting NextGen with regards to weather and weather integration. Several of the plenary speakers urged participants to "think outside the current ways of doing business" - be novel and non-traditional. The group broke into relatively small working groups to address the issues of policy, research, planning, simulations, demonstrations and metrics with regard to weather integration within each of the four major pillars of NextGen – Trajectory Based Operations, Super Density Operations,

Surface Airport Operations, and Net-Centric availability and access to common weather information.

A common theme that prevailed across the working groups was that while the language in the NextGen Concept of Operations (ConOps) has been embraced by all National Airspace System (NAS) stakeholders, there are several considerations towards the reduction of weather impact that must be taken into account before many of the envisioned operational (non-weather) benefits are realized. These involve operational constructs and nuances as perceived by the intended user of the information. Such considerations (i.e., where the rubber meets the road) go beyond any specific scientific improvements in weather understanding and behavior, airborne or ground-based weather sensor density, weather forecast skill or modeling and ultimate weather integration. These considerations include how and when the information is presented, the consistency of the information among differing operators, common interpretation of the information in terms that are relevant to the operation, and the risks or consequences (real or perceived) of the use of the information. There was general agreement that the most important considerations of all will be the policies that facilitate change, the regulations that dictate change, and the transitional stages in operations that will enable operational evolution (e.g., continuity of services/conservation of functionality) while providing perceived benefits and safety. The general consensus of the participants in the NextGen Weather work group determined that while network enabled digital data is a key to success, there was a lack of clarity and messaging (outside the Joint Planning and Development Office (JPDO)) regarding government and industry roles for populating and operating the weather 4D Wx Data Cube. Weather dissemination to, and access by, aircraft is also vital to satisfying the 'aircraft as nodes on the net' concept. Industry is prepared to join the government in identifying options to make NextGen Weather a reality.

6.3 Integration Teams Approach to Tracking the Status on the Previous Findings and Recommendations

The Weather Integration Team has developed a spread sheet to track the stat of the major findings and recommendations from these two groups. The spreadsheet is contained in Appendix D.

6.4 Agency Approaches to Implementing the Findings and Recommendations

In the NextGen concept, weather information used by ATM decision-makers will come from a net-centric, virtual, data repository of aviation weather data, referred to as the "four-dimensional weather data cube." This concept allows each Federal agency to leverage and merge their existing agency-specific efforts and aviation-weather requirements into a mutually supportable national and eventually global, construct. This Federal effort addresses a way to combine public and private sector aviation weather needs into the ATM process as well as allowing each agency to maintain various independent capabilities consistent with their own weather needs. The weather communities within NOAA, FAA, DoD have developed a plan to ensure accessible, network-enabled weather information will be available to meet the user's integration/operation needs.

Currently, the FAA is the lead agency charged with developing integration tools. The FAA's NextGen Implementation Plan (NIP) includes the Reduce Weather Impact (RWI) Program.

Activities in the near term will focus on: developing a concept of use and initial requirements for weather dissemination; preparing for and conducting a weather dissemination interoperability demonstration; developing a concept of use and requirements for weather information needed by manual and automated traffic management and cockpit decision-support tools; assessing gaps and redundancies in the current aviation weather observation networks; development of a pre-prototype multifunction phased array radar; and development of improved forecasts (e.g., convection, turbulence, icing).