DEVELOPMENT AND APPLICATION OF A CLASSIFICATION SYSTEM FOR COMPARING FUTURE AIR TRAFFIC MANAGEMENT OPERATIONAL CONCEPTS

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Abstract

As the Federal Aviation Administration (FAA) moves forward with plans to evolve operations of the National Airspace System (NAS), as well as to achieve the various operational improvements described by the Next Generation Air Transportation System (NextGen) Implementation Plan [1], there is an increasing need to assess a broad range of solutions in a systematic manner to determine which will prove most desirable for implementation. Discriminating between these concepts can be a difficult task because of the variability in the level of detail that exists and the different Air Traffic Management (ATM) aspects that are described. Understanding these differences is important because of their far-reaching impact to the NAS evolution path.

This paper seeks to provide an evaluation framework for comparing future ATM arrival/departure concept alternatives. The framework is based upon review of a sample of concept descriptions, proposed by industry, academia, and government, that was conducted to understand the wide variability of aspects addressed. The framework involves applying questions that can decompose concepts into more abstract terms so that features and critical parameters can be highlighted to help identify concept commonalities (and differences). A classification system is proposed for organizing the arrival/departure concepts. Using this classification system, a mapping of the arrival/departure concepts within the taxonomy described was performed.

Introduction

Many alternative concepts, that introduce or leverage new technologies and exist in different states of maturity (i.e., some concepts are currently in operational trials while others are not), have been proposed for future ATM to improve upon today's operations. These concepts are often driven by distinct needs such as rising operator costs, increased environmental demand, and forecasted traffic growth. As the FAA moves forward with plans to evolve operations of the NAS, as well as to achieve the various operational improvements described by the NextGen Implementation Plan [1], there is an increasing need to assess a broad range of solutions in a systematic manner to determine which will prove to be most desirable for implementation. Discriminating between these concepts can be a difficult task because of the variability in the level of detail addressed, the lack of a standardized description employed (i.e., the different ATM aspects described), the different objectives being served (i.e., some concepts use different tools and capabilities to achieve similar objectives while other concepts use similar tools and capabilities to achieve different objectives), and inconsistent or new terminology utilized. These things can obscure or convolute concept relationships with each other as well as concept compatibility with existing/fielded ATM tools and capabilities. Understanding these differences is important because of their far-reaching impact to the NAS evolution path.

In an effort to facilitate this understanding, a classification system for comparing ATM concept alternatives is provided. A two-prong approach, built upon the use of criteria and terminology intended to be commonly applied across concepts, is used to identify key concept relationships. The first prong involves an applied set of questions, developed around the use of abstract terms, intended to highlight concept features and critical parameters, to organize concept information, and to help identify concept commonalities (and differences). Organizing concept information using these questions provides the basis for determining where the concept fits within a proposed classification system (second prong) comprised of six ATM facets. These six facets are 1) implementation timeframe, 2) operational characterization, 3) airspace environment, 4) aircraft separation task responsibility, 5) execution of the merging and spacing task, and 6) the scheduling and sequencing task. The classification system was formulated based upon a review of arrival/departure concepts conducted to understand the wide variability of aspects addressed by a sample of concept descriptions proposed by industry, academia, and government. Upon review of the arrival/departure concepts, a mapping to the proposed classification system has been performed. Concepts reviewed include departure and arrival scheduling concepts, efficient vertical descent profile concepts, arrival merging, sequencing, and spacing concepts, and end-to-end traffic management concepts. This paper will define the taxonomy used within the proposed classification system, identify the set of applied questions for concept detail organization, and present a mapping of the reviewed arrival/departure operational concepts into the classification system.

Operational Concepts Reviewed

A sample of twenty arrival/departure operational concept descriptions was reviewed (see Table 1). Since a mapping of these concepts to the classification system proposed will be identified in this paper, a reference to a figure (Figure 1) which will be presented later is also provided.

Table 1. Arrival/Departure Operational Concepts Reviewed

Operational Concept Name	**Figure 1 Reference**
Los Angeles and Phoenix Approach Concept [2]	1
Houston Approach Concept [2, 3]	2
Atlanta and Miami Approach Concept [4]	3
Southern California and United Kingdom Area Navigation (RNAV) and Required Navigation Performance (RNP) Approach Concept [2]	4
Performance-Based Air Traffic Management Terminal Concept of Operations [5]	5
Terminal Area Required Time of Arrival (RTA) Concept of Operations [6]	6
Performance-Based Air Traffic Management (ATM) Concept (end-to-end target state) [7]	7
An Advanced Concept for Terminal Operations [8]	8
Boeing Tailored Arrivals; Near-Term Concept [2, 9]	9
Boeing Tailored Arrivals; Far-Term Concept [2, 9]	10
Stockholm Green Approaches [2]	11
Airline Based En Route Sequencing and Spacing (ABESS) [2, 10]	12
ABESS and Flight Deck Merging and Spacing (FDMS) Concept [2, 10, 11]	13
3D Path Arrival Management (PAM) Concept [12]	14
3D Path Arrival Management (PAM) Concept Extension for Terminal Radar Approach Control (TRACON) Operations [13]	15
Operations Managed Using Center TRACON Automation System (CTAS) [14]	16
Integrated Arrival/Departure Airspace Management Concept [15, 16]	17
Distributed Air Ground Traffic Management (DAG-TM) [17]	18
Integrated Equivalent Visual Operations (EVO) Concept [18]	19
Logical Expansion of Arrivals and Departures to Enhance RNP (LEADER) [19]	20

Making Concept Comparisons

Since these concepts are not described uniformly, it can be difficult to understand inherent differences implied among them and also to establish relationships between concepts. In other words, can some concepts co-exist within the same environment or do some concepts violate one another? In addition to providing a concept description summary, identifying the primary objectives intended by each concept, and, where possible, identifying a site case study or evaluation (e.g., human in the loop simulation or other validation activity) example, a set of questions was applied to each concept description to tease out subtleties that can be used to differentiate between them. Collectively, these were all intended to better qualify concept descriptions to facilitate a better and more easily acquired understanding of the differences. These questions were used in part to formulate a proposed classification system that will be later described. The questions were determined by analyzing the concept descriptions and focusing on isolating differences existing among them.

The set of questions applied is listed below:

- What is the vertical descent profile classification[1]?
- Where or at what point does the efficient vertical descent profile begin (e.g., Top of Descent)?
- How are aircraft sequenced or scheduled over an arrival/departure meter point fix?
- Is there a requirement to develop a schedule for departure operations different from how this is accomplished today? If yes, how is the schedule compiled and executed?
- Does the concept describe use of time-based metering? If yes, are enhancements to Traffic Management Advisor (TMA) required to support the concept?
- How is aircraft merging and spacing accomplished?
- How is aircraft separation maintained?
- Are aircraft assigned or instructed to meet a time at some point in space (e.g., RTA at a waypoint) to accomplish the merge of converging traffic flows?
- Are aircraft assigned or instructed to meet a time (i.e., agreed to contract) at the runway threshold?
- Do arrival/departure operations use a set (or sets) of common or pre-defined lateral paths to move to and from airports?
- What is the level of lateral path stability?
- Does the airspace design preserve airspace for crossing traffic flows?
- How is the aircraft trajectory calculated?
- What is the minimum requirement for coordinating trajectory information with aircraft?
- Does the concept require real-time electronic sharing of information between the ground and flight deck?
- Does the concept require trajectory negotiations with the ground?
- Are trajectories checked in advance by automation to be conflict-free?
- Does the concept require flight deck display of traffic information?
- Does the concept describe using automation for problem prediction or resolution capabilities?
- Does the concept explicitly change conflict probe requirements (i.e., different from the User Request Evaluation Tool (URET) as fielded within the Host Computer System (HCS) today)?
- Does the concept describe using automation to detect aircraft conformance to the procedure or trajectory?

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[1] In addition to the category of Non-Continuous Descent Arrival (CDA), described as arrival operations performed by complying with altitude instructions and level segments as required, the differences between efficient descent profiles were made using the following defined categories: Baseline CDA, CDA from an Intermediate Altitude (CDAIA), Non-Idle Descent Variation of CDA, and Interrupted CDA Variation [2].

- Does the concept require improved surveillance information such as Automatic Dependent Surveillance-Broadcast (ADS-B) capability?
- When ground automation is used, what is the format of the trajectory information or clearance issued to the flight deck?
- What are the potential performance limitations of the concept (e.g., equipage, traffic level, staffing)?

This set of questions was applied to each concept reviewed. Initially, as more concepts were reviewed the set would grow. A complete (or near-complete) set of distinguishing questions was considered achieved based on the measure of question set stability or in other words, once the set of questions stopped growing with each new concept reviewed. Comparing concept alternatives in other domains (e.g., oceanic) would likely yield a different set of questions.

A Proposed Classification System

It was in the process of reviewing the different operational concepts, that certain aspects were revealed that could be use to more easily differentiate among ATM concept alternatives. The review led to a derivation of six distinct facets that could be used to organize concepts at a higher level but in a meaningful way so comparisons could be made relative to each other. These facets are 1) implementation timeframe, 2) operational characterization, 3) airspace environment, 4) separation responsibility, 5) merging and spacing task, and 6) scheduling and sequencing task. Implementation timeframe was directly based on that identified within the operational concept description; no judgment of implementation expectation was made. Timeframe categories of near- (2008-2012), mid- (2012-2018), and far- (2018 plus) term were utilized. For the other facets, defined groupings were derived based on the sample of operational concepts reviewed. Definitions for each facet are presented and described.

Operational Characterization

This facet represents a critical distinction among concepts; whether the concept resides upon time-based control or relative spacing control initiatives. Simultaneously achieving both ATM principles is not possible as they are at odds with each other. The following definitions were proposed to group concepts so they could be distinguished.

- 4D Trajectory Operation: Operational objective is to maintain/achieve a determined schedule. Unscheduled or unplanned time drifts are not permitted.
- Relative Spacing Operation: Operational objective is to maintain consistent spacing between aircraft even if the absolute scheduled time value (determined to achieve the spacing) drifts.

Environment Description

The magnitude of flexibility described for operations varied widely between the concepts reviewed. Among the concepts, two major distinctions could be made with differences still existing; they were Structured and Unstructured Environments. Concepts categorized as a Structured Environment included traffic operations that reflected a prevalent use of published or fixed routings while an Unstructured Environment did not. The following definitions are proposed to organize concepts with varying degrees of structure.

- Structured, Ad Hoc Routing and Paths: Use of conventional procedures or the frequent use of “dynamic” path variations from a nominal procedure (e.g., vectors or pilot defined waypoints)
- Structured, Medium Path Predictability: Use of RNAV and RNP procedures (lateral path only). An example is paths that enable CDAs or CDA variations.
- Structured, High Path Predictability: Use of RNAV and RNP procedures with altitude constraints at waypoints. Execution of the aircraft’s flight path is known with a fair level of confidence in at least three dimensions. An example is paths that enable Optimized Profile Descents.
- Structured, Very High Path Predictability: Use of well-defined

procedures that include flying a specific glide path (e.g., Three-Dimensional (3D) RNP). This path will not differ between subsequent aircraft.

- Unstructured, Trajectory-Based: Use of this term is intended to reflect that the aircraft has filed a specific known path in space composed of a series of latitude and longitude points. This path will likely differ between subsequent aircraft but the path for each aircraft is known by ATC.
- Unstructured, Free Flight: Use of this term is intended to reflect the lack of a requirement for aircraft to file a specific flight path in space. This path will differ between subsequent aircraft.

Separation Responsibility

Another very important difference by which to organize concepts involves who (or what) holds responsibility for providing separation. Many (but not all) concepts introduce changes to today's responsibility paradigm based on newly available automation and/or advanced capabilities on the flight deck. Five conceivable new groupings were derived and are defined below.

- Positive Control: A form of ground-based separation responsibility. The separation of all air traffic by ATC within designated airspace using existing/fielded separation tools. This grouping is intended to reflect responsibility as it is defined for today's operations.
- Enhanced Positive Control: A form of ground-based separation responsibility. Similar to Positive Control, except part(s) of the separation task are assisted through implementation of new tools as described by the given operational concept. The controller is responsible for the problem prediction and resolution task. The availability of any automated tools is for assisting the controller with early detection of events or for decision-making when completing the problem prediction and resolution task.
- Automation-Assisted Positive Control: A form of mixed ground separation responsibility. The use of this term reflects when the controller task of problem prediction is assisted by ground-based automation. The automation is fully responsible for predicting problems while the controller remains responsible for resolving problems once they have been identified by automation.
- Blended Separation: The aircraft and ground share different roles in the separation task (e.g., ground delegation to the flight deck for pair-wise separation). In this case the pilot is responsible for separating own ship from target aircraft(s) using procedures, tools/capabilities, or a mix of both.
- Aircraft Self Separation: This term encompasses aircraft-based separation responsibility. The pilot is responsible for separating own ship from other traffic using procedures, tools/capabilities, or a mix of both. The pilot (and not the controller) is responsible for problem prediction and resolution.
- Automated Separation: Use of this term is intended to describe a fully autonomous system. Automation is responsible for problem prediction and resolution.

Merging and Spacing Task

Within the concepts reviewed, responsibility for the merging and spacing task varied between the controller and the flight deck. This task is intended to describe the execution of decisions and implementation of solutions to maintain an appropriate spacing interval for merging or in-trail operations that is greater than the separation minima required. Four categories are proposed to describe this relationship.

- Ground-Centric Responsibility, Existing: Air traffic controllers with or without the assistance of existing/fielded ATC tools accomplish the merging and spacing task.

- Ground-Centric Responsibility, Enhanced: Air traffic controllers along with the use of new ATC decision support tools accomplish the merging and spacing task in conjunction with or without utilizing existing/fielded ATC tools.
- Aircraft-Centric Responsibility: The pilot with or without the assistance of flight deck tools identifies, generates, and executes solutions for the merging and spacing task.
- Blended Responsibility: The aircraft and ground share roles in the identification, generation, and execution of solutions for the merging and spacing task.

Sequencing and Scheduling Task

Another important dimension of ATC operations that is highly correlated with the merging and spacing task is how (i.e., by what means) operations are scheduled and sequenced. Today, for airports where demand exceeds capacity, a schedule is compiled using flow management tools like time-based metering. Controllers aim to meet the traffic schedule but can also re-sequence traffic as appropriate to account for other considerations, like wake separation, that can optimize efficiency of operations. This facet was generally not very well-described given the operational concepts that were reviewed. Three distinctions were made to provide a simple organization of concepts along this facet. They involve use of existing capabilities, introduction of new capabilities, and unspecified capabilities. Since this facet was not always well-described, the third category was incorporated to identify concepts where this dimension was unknown. In some cases there was not enough information to make a distinction, perhaps because the concept was designed to be flexible in this regard. The following definitions for this facet are proposed.

- Existing Capability: Concept describes utilizing an existing/fielded automated scheduling capability such as time-based metering. This category assumes a ground-based schedule and sequence compilation.
- New Capability: Concept introduces a new scheduling capability or requires an enhancement to an existing/fielded automated capability. This category assumes a ground-based schedule and sequence compilation.
- Unspecified Capability: The concept does not specify the requirement for or utilization of a ground-based automated scheduling or sequencing capability.

Classification System Mapping

A mapping of the twenty concepts reviewed in the process of formulating the classification system is provided below in Figure 1. These relationships are based on the documentation cited for each concept. The asterisk (*) symbol was employed as follows to notate the sequencing and scheduling task classification; * to reflect Existing Capability status, ** to reflect New Capability status, and no asterisk to reflect Unspecified Capability status. Additionally, distinctions were made for more end-to-end concepts when a given mapping only applied to a limited aspect or domain described by the concept. A capital „T' was used to denote when a concept classification only applied to airspace operations contained within a typical TRACON boundary or between the meter point fix and the runway. A capital „E' was used to denote when a given concept classification only applied to cruise operations and operations between the Top of Descent and the meter point fix (or TRACON airspace boundary). As concepts are expanded, refined, or otherwise modified, the set of questions should be revisited and the standing of a given concept should be updated as appropriate.

Separation Responsibility		Merging and Spacing Task Responsibility	4D Trajectory: Ground-Centric: Existing	4D Trajectory: Ground-Centric: Enhanced (1)	4D Trajectory: Ground-Centric: Enhanced (2)	4D Trajectory: Aircraft-Centric	4D Trajectory: Blended (1)	4D Trajectory: Blended (2)	Relative Spacing: Ground-Centric: Existing (1)	Relative Spacing: Ground-Centric: Existing (2)	Relative Spacing: Ground-Centric: Existing (3)	Relative Spacing: Ground-Centric: Existing (4)	Relative Spacing: Ground-Centric: Existing (5)	Relative Spacing: Ground-Centric: Enhanced (1)	Relative Spacing: Ground-Centric: Enhanced (2)	Relative Spacing: Ground-Centric: Enhanced (3)	Relative Spacing: Ground-Centric: Enhanced (4)	Relative Spacing: Aircraft-Centric	Relative Spacing: Blended
Structured	Positive Control	Ad Hoc Routing and Paths		14**E	15**E								14**T	12**					
Structured	Positive Control	Medium Path Predictability		9E	20**				1	17**T	3**	4	14**T	12**	2*				13**
Structured	Positive Control	High Path Predictability			20**				9T	17**T		15**T	14**T	12**	2*	6*	16**	13**	13**
Structured	Positive Control	Very High Path Predictability			20**					17**T		15**T	14**T	12**	2*	6*	16**	13**	
Structured	Enhanced Positive Control	Ad Hoc Routing and Paths												12**			5*		
Structured	Enhanced Positive Control	Medium Path Predictability		7**T	8**		7**T	8**		17**E				12**					
Structured	Enhanced Positive Control	High Path Predictability		7**T	8**		7**T	8**		17**E				12**			5*		
Structured	Enhanced Positive Control	Very High Path Predictability		7**T	8**		7**T	8**		17**E				12**			5*		
Structured	Automation Assisted Positive Control	Ad Hoc Routing and Paths												12**					
Structured	Automation Assisted Positive Control	Medium Path Predictability												12**					
Structured	Automation Assisted Positive Control	High Path Predictability												12**					
Structured	Automation Assisted Positive Control	Very High Path Predictability												12**					
Structured	Blended Separation	Ad Hoc Routing and Paths												12**					
Structured	Blended Separation	Medium Path Predictability				11								12**				19	
Structured	Blended Separation	High Path Predictability				11								12**				19	
Structured	Blended Separation	Very High Path Predictability												12**				19	
Structured	Aircraft Self Separation	Ad Hoc Routing and Paths												12**					
Structured	Aircraft Self Separation	Medium Path Predictability												12**					
Structured	Aircraft Self Separation	High Path Predictability												12**					
Structured	Aircraft Self Separation	Very High Path Predictability												12**					
Structured	Automated Separation	Ad Hoc Routing and Paths												12**					
Structured	Automated Separation	Medium Path Predictability												12**					
Structured	Automated Separation	High Path Predictability												12**					
Structured	Automated Separation	Very High Path Predictability												12**					
Unstructured	Positive Control	Trajectory-Based		18**															18
Unstructured	Positive Control	Free Flight																	
Unstructured	Enhanced Positive Control	Trajectory-Based		10E	10T														
Unstructured	Enhanced Positive Control	Free Flight																	
Unstructured	Automation Assisted Positive Control	Trajectory-Based		7**E															
Unstructured	Automation Assisted Positive Control	Free Flight																	
Unstructured	Blended Separation	Trajectory-Based																	
Unstructured	Blended Separation	Free Flight																	
Unstructured	Aircraft Self-Separation	Trajectory-Based																	
Unstructured	Aircraft Self-Separation	Free Flight				18													
Unstructured	Automated Separation	Trajectory-Based																	
Unstructured	Automated Separation	Free Flight																	

Figure 1: Mapping of reviewed concepts to the proposed classification system.

Conclusion

An understanding of how these future operational concepts fulfill FAA initiatives, interact with existing operations, infrastructure, and aircraft equipment, as well as integrate with each other is imperative to continuing safe, efficient, and effective operations across the NAS. The framework proposed will enable a „tradeoff space' assessment of these concepts to help evaluate the viability and scalability of these solutions and, ultimately, promote a more concise and clear understanding to base investment decisions upon. Although only arrival/departure related operational concepts are reviewed, the framework described could be used as a basis for mapping additional concept types (e.g., more en-route centric concepts).

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