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Potential NAS Transition Strategies for Distributed Air/Ground Concept Elements CE-5 En Route Free Maneuvering CE-6 En Route Trajectory Negotiation and CE-7 En route Collaboration

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1. Introduction and Scope

This document presents the preliminary transition strategies for AATT Distributed Air/Ground Traffic Management (DAG-TM) Concept Elements 5, 6, and 7 (CE-5, CE-6, and CE-7) [Ref.1-6] and an integrated transition strategy for all three Concept Elements.

2. Distributed Air/Ground Individual Concept Element Transition Plans

2.1 CE-5 En Route Free Maneuvering Transition Plan

2.1.1 CE-5 Concept Overview [Ref. 4]

As stated in the Concept Definition for DAG-TM [Ref.1]:

Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local traffic flow management (TFM) constraints.

Free maneuvering aircraft are those that (1) are appropriately equipped, (2) have responsibility for self-separation, and (3) have been granted the authority, capability and procedures needed to execute user-preferred trajectory changes without requesting Air Traffic Service Provider (ATSP) clearance to do so. Along with this authority, the flight crew takes on the responsibility to ensure that the trajectory change does not generate near-term conflicts with other aircraft in the vicinity. Free maneuvering aircraft continue to follow defined air traffic rules and procedures as is true of all aircraft.

Free maneuvering will allow aircraft to fly more optimized user-preferred trajectories. Under the CE-5 concept, which takes place in the en route operational domain, flight crews have the authority, tools, and infrastructure necessary to provide their own solutions to traffic conflicts and localized TFM constraints imposed by the ATSP. Such constraints will continue to occur throughout en route airspace; examples are en route metering, miles in trail, and required times of arrival (RTA) in transition.

A user-preferred trajectory modification may be generated by the flight crew, or if time permits it may be created by the Airline Operations Center (AOC) and transmitted to the flight crew via datalink. The flight crew instructs the aircraft's flight management system (FMS) to initiate the trajectory, and at the same time on-board automation broadcasts the modified trajectory using automatic dependent surveillance to the ATSP and to other aircraft.

The controller role changes significantly under the CE-5 concept. The controller retains responsibility for all aircraft which are not free maneuvering, called *managed*. The controller uses Conflict Detection and Resolution (CD&R) decision support tools to maintain separation assurance for managed aircraft, and also to monitor the activities of all aircraft. In the case of a potential conflict between a managed and a free maneuvering aircraft, procedures and flight rules are followed by the free maneuvering aircraft and the controller acting on behalf of the managed aircraft. In order to provide an incentive for aircraft to equip for free maneuvering capability, flight rules include priority status for free maneuvering aircraft in conflicts with managed aircraft.

The traffic management coordinator (TMC) continues to set localized TFM constraints as today. Potential changes in the TMC role are a subject for research.

Free maneuvering addresses the following problems of today's en route Air Traffic Management (ATM) environment which motivated the development of the CE-5 concept.

Trajectory Prediction Uncertainty

To solve anticipated air traffic conflict situations, future aircraft trajectories must be predicted. The accuracy of these predictions determines the breadth of resolution options available. If trajectory predictions are inaccurate, resolution options involving legal, but closer separation are unavailable. These limitations in resolution options contribute to deviations from user-preferred trajectories. Instead of a user being able to fly a user-preferred trajectory with small deviations for traffic constraints, the user may have to fly a trajectory with much larger deviations to accommodate the uncertainty of ownship trajectory as well as other traffic trajectories.

Certain characteristics of current air traffic systems are the cause of trajectory prediction uncertainty. The first is that trajectory adjustments made while en route are based on a sector-oriented viewpoint, as opposed to a whole-trajectory viewpoint. This segregation of a trajectory into sector-defined portions means that trajectory adjustments that will be made in future sectors are difficult to predict.

A second cause of uncertainty is the lack of accurate information about the future air traffic environment. First, the actual trajectories followed by aircraft are often not known in the future, because the trajectories will change due to unanticipated conflicts. Second, airspace restriction areas due to weather or congestion are not known accurately because of the dynamic nature of these area hazards. Third, there is imperfect knowledge of wind fields. Fourth, future aircraft intent information is not readily accessible. Within a given sector, a controller can anticipate the resolution maneuvers that will be needed, and, therefore, the intent of the aircraft. However intent information for downstream sectors is not readily accessible, since different controllers are involved in resolutions for these sectors. Lastly, future trajectory predictions are not displayed effectively. Currently, the ATSP has access to a tool that shows a projection of an aircraft's predicted path for a short look-ahead time, but not for an entire trajectory.

ATSP Workload Limitations

Currently, the ATSP must provide all separation services necessary for an Instrument Flight Rules (IFR) flight's safety. These tasks include trajectory prediction, conflict detection and resolution, local traffic flow constraint conformance, trajectory adjustments, and flight plan conformance monitoring.

The root cause of ATSP workload limitations is that the ATSP has responsibility for multiple aircraft. Therefore, the ATSP often cannot monitor individual aircraft for long periods of time, and cannot provide individual aircraft the ability to follow user-preferred trajectories.

Furthermore, as more aircraft come under the jurisdiction of the ATSP, each aircraft will have less share of the controller's attention. As traffic density increases, the ability to implement user-preferred trajectories decreases.

Lack of User-Preference Knowledge for Resolutions
Flight plans are filed at the beginning of a flight, and often must be changed en route because of conflict situations or adherence to local traffic flow constraints. En-route adjustments to a flight's trajectory are often made without knowledge of user preferences.

2.1.2 CE-5 Operational Environment Evolution

2.1.2.1 Airspace Structure and Constraints

En route free maneuvering is designed for domestic en-route airspace, although many aspects of the concept element could apply to low-density terminal departure and arrival domains, as well as oceanic and international airspace. It will need to operate in unconstrained, constrained, and transition airspace. Unconstrained airspace is a situation where free maneuvering aircraft need make no trajectory adjustments away from user-preferred trajectories except for separation assurance. Constrained airspace includes the following kinds of constraints on user trajectories:

- TFM initiatives
    - traffic volume restrictions
    - flow rate assignments
- Area hazards
    - weather
    - Special Use Airspace (SUA)

Transition airspace is that portion of en-route airspace immediately outside terminal airspace, within which arriving aircraft are conducting significant descents to their arrival routes and departing aircraft are conducting significant climbs to cruise.

It is assumed that a route structure may exist in the CE-5 environment, along with a system of named waypoints. The latter are used for easy communication of locations. However, free maneuvering aircraft are no longer required to follow the routes. These aircraft may also perform cruise climbs and do not need to adhere to cardinal altitude rules.

Research will determine a set of feasible procedures for Air Traffic Control (ATC) to direct "managed" aircraft, including the use of cardinal altitudes and fixed route structures. Initially, it is assumed that managed aircraft follow current cardinal altitude standards and fixed route structures.

The concept of "managed only" airspace may be brought into CE-5. In this airspace, aircraft may only operate if they are managed.

2.1.2.2 Traffic Mix and Equipage

There are two types of aircraft: free maneuvering and managed. Free maneuvering aircraft have automation enabling situation awareness, self-separation, and trajectory re-planning. These aircraft have the authority to make trajectory changes with the restriction that no new conflicts be created within a defined period of time (e.g., 8 minutes) by their maneuvers. The appropriate time horizon is a subject of research. They must transmit their position and intent to enable conflict detection and resolution by other free maneuvering aircraft and the ATSP.

Free maneuvering aircraft voluntarily equip themselves for self-separation and trajectory re-planning and, by doing so, achieve the benefits while assuming additional responsibilities. These aircraft have the baseline equipage requirements for today's en route airspace. Required additional equipage includes:

- flight management system
- datalink
- interactive, multifunctional cockpit display
- automatic dependent surveillance
- decision support
    - conflict detection and resolution
    - trajectory re-planning
- Traffic Alert and Collision Avoidance System (TCAS)

All types of aircraft (e.g., air carrier, general aviation, corporate and military) may be free maneuvering. The concept allows, but does not require, association with an AOC. Global interoperability will be a design goal for the free maneuvering aircraft capability.

Managed aircraft continue to be controlled by ATC in a similar manner as today. The concept of managed aircraft equipage is still evolving. In addition to the requirements for today's en route airspace, managed aircraft of the future may choose to obtain some of the equipage that will be required for free maneuvering aircraft, in order to achieve benefits such as increased situation awareness and improved data communications.

2.1.2.3 CNS Infrastructure

Datalink is the principal addition to today's communications infrastructure. There are two kinds of ground to air datalink: addressed, for specific constraints, and broadcast, for messages of general interest. Addressed datalink messages to free maneuvering aircraft include controller advisories and traffic management directives for the aircraft, such as commitment to a RTA. Broadcast messages include weather and SUA advisories. Air to ground datalink will be used for pilot acknowledgements.

The Global Positioning System (GPS) is certified for en route navigation. For surveillance to operate effectively, a free maneuvering aircraft must know its own state with significant accuracy including its position which is obtained by reading from a GPS receiver. This state (including position and velocity) and the aircraft's intent must be broadcast regularly via automatic dependent surveillance.

The surveillance broadcast needs to be received by nearby free maneuvering aircraft and also by the ATSP on the ground. This information along with comparable information on managed aircraft is broadcast ground-to-air as traffic information to all free maneuvering aircraft in that region.

2.1.2.4 ATM Environment

An advanced decision support system, operating in conjunction with the controller display, is essential for the controller. This will provide a high level of situation awareness, along with a CD&R capability to anticipate conflicts and to implement conflict-free resolutions as required. For the controller to have the most current aircraft intent information as part of decision support, the ATSP automation must have a data fusion capability which includes radar, Host flight plan, and aircraft state and intent information from aircraft broadcast.

The CE-5 concept does not require any change in strategic traffic management, although changes as a result of CE-5 may be beneficial. Further research is needed to demonstrate whether changes in local traffic management, either in automation or procedures or both, are required or beneficial.

2.1.3 CE-5 Enabling Technologies

Enabling technologies for the CE-5 concept are classified into those applying to the flight deck, and those applying to the ground infrastructure. The schedules for these capabilities are taken from the NAS Architecture 4.0 document [Ref. 7] These schedules are indicated as Phase 1, Phase 2 or Phase 3 of the NAS Architecture process. Nominal dates associated with these phases are: Phase 1, through 2002; Phase 2, 2003-2007; and Phase 3, 2008-2015. This Transition Plan is designed for CE-5 operational capability in 2015.

2.1.3.1 Avionics

2.1.3.1.1 ADS-B

The CE-5 concept requires that free maneuvering aircraft are equipped with automatic dependent surveillance-broadcast (ADS-B) to broadcast current and frequently updated state and intent information for reception by other nearby free maneuvering aircraft. This supports accurate conflict detection and resolution between pairs of free maneuvering aircraft.

Air-to-air ADS-B becomes operational in Phase 1. This enables some self-separation by equipped aircraft using ADS-B and cockpit display of traffic information (CDTI) and, in selected areas, TIS.

2.1.3.1.2 Flight deck situation awareness and decision support

First, the flight crew needs decision support for trajectory optimization. This is already present in the aircraft's FMS and is progressively improving. Second, multifunctional cockpit displays are required. These are continuing to be developed by private vendors to integrate data and information from Traffic Information Service (TIS), Flight Information Service (FIS), ADS-B etc. and provide moving maps, traffic, ATC messages and related information. These are available in Phase 1 and 2. Third, the flight crew needs decision support for self-separation, which becomes available in Phase 2 and 3.

2.1.3.1.3 Weather

The principal requirement of the CE-5 concept is improved weather and wind products to the flight deck, to enable accuracy both in CD&R and in trajectory re-planning. In the NAS architecture, the scope and accuracy of weather products increases through the three phases. In Phase 1, common weather data becomes available to private vendors, is transmitted via FIS, and is displayed to the flight crew in aircraft equipped with the appropriate display.

In Phase 2, additional weather products are supplied including improved weather radar information, hazardous weather advisories, observations and forecasts, winds and temperatures aloft, gridded forecast data, and pilot reports. This weather information becomes tailored to display significant weather along the flight path.

In Phase 3, the following further improved weather products become available: freezing level, wake turbulence, ceiling/visibility, and volcanic ash cloud forecasts. Weather and winds become four dimensional (4D) gridded products. Adequate radio frequency bandwidth is required for gridded weather and wind products to be sent via FIS in sufficient detail to support free maneuvering operations.

2.1.3.2 Infrastructure and Automation

2.1.3.2.1 CPDLC

CPDLC Builds 2 and 3 via the FAA's next-generation air-ground communications (NEXCOM) network using very-high-frequency data link (VDL) Mode 3 is required for the CE-5 concept because of its capability for time-critical communications lacking in previous versions. This becomes available in Phase 3. Required messages from the controller to the pilot of a free maneuvering aircraft are aircraft-specific advisories and flow constraints such as RTAs. Required messages from the pilot of a free maneuvering aircraft to the controller include negotiations concerning flow constraints, message received, and accept/reject action.

2.1.3.2.2 FIS

In Phase 1 and 2 of the NAS architecture, initial information on NAS operational and maintenance status, SUA, and weather from commercial providers is broadcast via Flight Information Service–Broadcast (FIS-B). In Phase 3, comprehensive NAS-wide information from a mix of private and government sources becomes available and broadcast including advisories on SUAs, congested areas, flow constraints and weather.

2.1.3.2.3 TIS

In Phase 1 and 2, surveillance information collected by the ATSP on the ground is broadcast at selected sites using Traffic Information Service-Broadcast (TIS-B). The CE-5 concept requires full awareness of all traffic surrounding a free maneuvering aircraft, which becomes available in Phase 3 through comprehensive coverage of airspace by TIS-B and a NAS-wide data link.

2.1.3.2.4 ADS-B

In Phase 2, Mode-S is upgraded with the ASTERIX message protocol for standard data communications between surveillance and automation systems. This enables ADS-B information return to ground control via Mode-S and the Ground-Initiated Communications Broadcast (GICB) message.

In Phase 3, a network of passive Automatic Dependent Surveillance (ADS) ground stations enables full ground surveillance of free maneuvering aircraft using ADS-B messages.

2.1.3.2.5 Flight object

The flight object is a more comprehensive data set about each flight than today's flight plan, and incorporates new data such as user preferences, aircraft data, trajectories and estimated times of arrival at waypoints. The flight object needs to be available and distributed NAS-wide, which occurs in Phase 3.

2.1.3.2.6 Controller situation awareness and decision support

In Phase 1, conflicts are indicated to the controller using the User Request Evaluation Tool (URET) conflict probe. In Phase 2, automation accepts ADS reports and includes this aircraft trajectory data in surveillance data fusion for improved situation awareness display to controllers. Also in Phase 2 improved decision support for the controller separation assurance function becomes available.

In Phase 3, the flight object is available for use by each controlling ATC facility as a flight passes through a series of en route centers. It is automatically updated by the controlling facility thereby remaining current. The flight object data combined with NAS data on hazardous weather and restricted airspace provides the basis for accurate and timely decision support for the controller to manage aircraft in a mixed equipage environment consisting of managed and free maneuvering aircraft.

2.1.3.2.7 Weather

The same scope and detail of weather information is available to the ATSP as to the free maneuvering flight crews. It is important that the data set be common to all users and the ATSP, so that during implicit coordination the different actors will perform as expected.

2.1.3.2.8 Traffic Management

Improvement in collaboration between the TMC and the flight crew, and use of the 4D flight object, would enable real-time user preferences to be incorporated into traffic management constraints. However, this is not part of the CE-5 concept; the concept can utilize traffic management directives in whatever form they may take.

2.1.4 CE-5 Other Requirements

The FAA's safety mission requires the agency to carry out certain regulatory and certification activities, concurrently with implementing changes to the NAS architecture and prior to initiating air traffic procedural changes. These are classified here into: procedures and rulemaking, equipment certification, and personnel training and certification.

Many of these requirements are challenging; however, they should not be on the critical path to implementing the CE-5 concept. The previous section has shown that several critical NAS architecture requirements for CE-5 become available only in Phase 3. One of these becomes available late in Phase 3, namely NAS-wide information distribution of the flight object and comprehensive TIS-B information to free maneuvering aircraft. Assuming a clear decision to implement the CE-5 concept, these non-architectural requirements can be accomplished concurrently with building the architecture.

2.1.4.1 Procedures and Rulemaking

Procedures and rulemaking occur in three areas: airspace design, ATSP procedures, and pilot procedures.

The FAA's Air Traffic Services (ATS) organization is responsible for airspace redesign. Strategic, system-wide changes to the airspace structure are required, to facilitate the new controller role and allow free maneuvering aircraft to follow new routes.

ATS develops controller procedures which are documented in FAA Order 7110.65, Air Traffic Control. Obviously these procedures need to be wholly revised to reflect the new controller role, which monitors activities of free maneuvering aircraft while managing other aircraft. They must clearly implement the separation of responsibility between controllers and pilots of free maneuvering aircraft which has been decided in the CE-5 concept, and the extent of controller authority.

The FAA's Regulation and Certification (AVR) organization's Flight Standards Service develops basic operating procedures for pilots. These are documented in Part 14, Code of Federal Regulations (CFR). At a minimum, new procedures are needed for pilots of free maneuvering aircraft to properly exercise self-separation and flight re-planning activities. These must also clearly implement the responsibilities of these pilots.

2.1.4.2 Equipment Certification

New and modified equipment must be certified in two areas: ATC equipment, and aircraft with airborne components.

ATS has a standard procedure for acceptance and certification of ATC equipment. This includes acceptance testing at the Technical Center, and installation and certification at each operational facility. For the CE-5 concept this process applies to controller decision support systems and new or modified displays.

AVR is responsible for certification both of new avionics and of the modified aircraft which is equipped with new avionics. This includes development of regulatory procedures, design, production and installation approvals for the aircraft modifications, and field office inspections of individual aircraft. A related activity is required maintenance activities for the equipment by aircraft owners.

2.1.4.3 Personnel Training and Certification

Personnel training and certification in the new operational procedures which were developed needs to be performed for ATSP personnel and pilots.

ATSP personnel need to be trained in the new procedures and re-certified. This has traditionally taken place under the direction of the Federal Aviation Administration (FAA) Academy at the Aeronautical Center.

For pilots there is a two-step process. Pilots who wish to become qualified for free maneuvering need to take instruction and training in a FAA-approved program, either within an airline or a private program. After training, certification occurs under the direction of AVR field offices.

2.1.5 CE-5 Consistency with Architecture 4.0

Figure 2.1-1, taken directly from the FAA NAS Architecture 4.0 [Ref. 7], summarizes the key technologies and systems which are planned during the FAA's NAS modernization program.

The enabling technologies described in Section 2.1.3 are with one exception part of the architecture, which has been planned to achieve free flight operations. The only CE-5 requirement not stated in the architecture is the cockpit automation and decision support necessary for free maneuvering, and this is entirely consistent with the architecture development.

2.1.6 CE-5 Transition Strategy and Schedules

The transition to the CE-5 concept most logically occurs in two main stages. These are early technology adoption and use, and full implementation. Early technology adoption and use is self-explanatory, under which flight crews become familiar with and gain benefits from the use of CE-5 technologies as they are naturally implemented, without free maneuvering. Full implementation consists of mixed managed and free maneuvering aircraft in the en route airspace.

2.1.6.1 Early Technology Adoption and Use

The discussion of this stage is divided into two parts: the technology implementation itself, and the early use of the increased flight deck capabilities that are made possible by the technology.

<u>Partial, progressively increasing implementation of FD/ATSP infrastructure</u>

<u>Communications.</u> In the evolution of the datalink service, an expanded message set that is ATN compliant becomes available in Phase 2.

The CPDLC service is planned in three builds. [Ref. 11] Build 1, which occurs in Phase 1, provides a lead-in test period that allows controllers and pilots to directly exchange a limited set of data link non-time-critical messages in the en route environment using VDL Mode 2. Build 1A, also in Phase 1, provides for national deployment of a limited set (18) of non-time-critical data link messages. Build 2 provides a further expansion of the message set which has become ATN compliant; this occurs in Phase 2. The exchange of messages provides user benefits in non-time-critical situations.

Via FIS, flight crews obtain initial information on NAS operational and maintenance status, SUA, and weather from commercial providers. Also TIS provides flight crews with surveillance information at selected sites. These capabilities are developed in Phases 1 and 2.