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MITRE TECHNICAL REPORT

Four-Dimensional Airspace Deconfliction MOIE Final Report

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Abstract

The Four-Dimensional Airspace Deconfliction (4DD) MOIE has been investigating airspace deconfliction concepts as they relate to military mission planning and mission execution monitoring, especially with respect to dynamic planning as will be encountered in planning time-critical strikes. The 4DD MOIE used as its inspiration airspace management concepts developed in MITRE's support to the Federal Aviation Administration by MITRE's Center for Advanced Aviation System Development (CAASD). This final report for the 4DD MOIE documents the history of the project and lessons learned during our investigations and prototyping efforts.

KEYWORDS: Four-Dimensional, 4DD, Airspace, Deconfliction, Airspace Deconfliction, Time-Critical Strike, Time-Critical Target, TCT, Conflict Detection, Conflict Probe, URET

Executive Summary

The 4DD MOIE was initiated in June of 1998 to explore airspace deconfliction concepts in support of dynamic planning or re-planning of time-critical strike missions. The MOIE specifically sought to investigate the fusion of air traffic control concepts and algorithms from civilian airspace management with those of military airspace monitoring and dynamic strike mission planning.

Airspace allocation to battle missions is currently performed using deliberative planning systems, such as CTAPS, the Contingency TAC (Tactical Air Command) Automated Planning System. Mission planners are then expected to adhere to assigned airspace corridor allocations. Modernization efforts seek to compress the deliberative planning cycle to the order of several hours. To effectively engage time-critical targets (TCTs) it is felt that airspace management that is primarily governed by assignment of air corridors is too restrictive. What is important for some air corridors in which missions are being flown is not avoidance of the air corridors by missions being dynamically planned to engage TCTs, but rather avoidance of the missions inside the corridors. The basic premise of the 4DD MOIE is that route-based airspace deconfliction or route conflict detection would provide more efficient use of airspace for the prosecution of TCTs.

The basic approach of the 4DD MOIE was to explore the use of air traffic control concepts that are evolving in the FAA in situations of military mission planning and mission execution monitoring. MITRE's Center for Advanced Aviation System Development (CAASD) has been investigating the insertion of systems and technology to aid air traffic controllers. The culmination of one of its many areas of research is URET, the User Request Evaluation Tool. A key feature of URET is that it provides controllers with an automated conflict probe capability to warn them of possible loss of minimum separation requirements in a window of time into the near future. Controllers can use URET to see upcoming conflicts between aircraft well before the conflicts become critical.

URET was demonstrated at Fleet Battle Experiment-Bravo (FBE-B) at the end of summer 1997 aboard the USS Coronado. Reaction to the notion of route-based airspace deconfliction in support of military activities was positive. This provided the impetus to propose and fund the research and experimentation of four-dimensional airspace deconfliction under MITRE's Mission Oriented Investigation and Experimentation (MOIE) research program.

From its outset, the 4DD MOIE has had an affiliation with the PMA-281 Strike Cell. The PMA-281 Strike Cell is a Command and Control (C2) systems integration and experimentation laboratory funded by PMA-281, the U.S. Navy Cruise Missile Command and Control Program, and implemented at MITRE facilities in Reston, VA. The 4DD MOIE developed software prototypes to participate in a variety of Strike Cell demonstrations in FY99 and FY00. The 4DD prototypes were used to provide surrogate route mission

planning capabilities and subsequently to demonstrate route-based conflict detection and visualization.

The 4DD MOIE developed a prototype in FY00 that was used to demonstrate the concepts of route-based airspace deconfliction. The software products of the 4DD MOIE that are available for use after the MOIE's completion for further demonstrations are the 4DD extensions to an existing visualization environment together with a conflict probe component called the CPGUI. The CPGUI can be used as a stand-alone component, as can another component, the CP daemon. They can be used for experimentation with existing C2 or mission planning systems to support CONOPS exploration or requirements derivation related to the use of route-based conflict detection and airspace deconfliction. Their use in experimentation would require additions or modifications to the C2 or mission planning systems that would use them.

In our 2+ years of demonstrations to audiences with time-critical strike interests, we have had the opportunity to discuss CONOPS and airspace deconfliction issues with a number of parties. Our prototyping efforts have also given us some insight into development and insertion of 4DD capabilities into Navy and DoD C2 architectures. The following summarizes some of the major observations and lessons learned during the 4DD MOIE:

- **URET itself is not modifiable for use as a military system**
- **URET-like functions or systems might be useful for military activities near civil airspaces**
- **No Navy programs have been given the charter to define requirements for and assume responsibility for airspace deconfliction activities to support time-critical strikes**
- **The "big sky little bullet" philosophy is still prevalent**
- **Route-based conflict detection support seems very applicable to mission planning**
- **Separation criteria for military situations would need to be developed**
- **Dissemination of route and mission information would require CONOPS exploration with regard to classification levels**
- **Development of a new Navy C2 system for airspace deconfliction is unlikely**
- **Issues of classification levels would have to be addressed by various systems receiving mission information**
- **Information in the COP would have to include route information**
- **Conflict probe in military use can probably be a simple proximity test**

- **Efforts to insert 4DD capabilities into existing C2 systems could be substantial, particularly for database access, network interfaces to other C2 systems, and user interface development**
- **Trajectory modeling in military conflict probe support can probably be simpler than in URET**

There are a number of possible activities that could be used to transition information and products from the 4DD MOIE to Navy programs and to further explore 4DD concepts within Navy programs. These activities fall into the following general categories:

- The 4DD prototype in MITRE's Reston facilities can be used for future demonstrations to Navy or other Service's personnel
- Some of the 4DD prototype's components can be used for limited experimentation with existing C2 or mission planning systems
- Requirements analysis, CONOPS exploration, architectural analysis with Navy program offices and their contractors

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Section 1

History of the 4DD MOIE

The 4DD MOIE was initiated in June of 1998 to explore airspace deconfliction concepts in support of dynamic planning or re-planning of time-critical strike missions. The MOIE specifically sought to investigate the fusion of air traffic control concepts and algorithms from civilian airspace management with those of military airspace monitoring and dynamic strike mission planning.

Airspace allocation to battle missions is currently performed using deliberative planning systems, such as CTAPS, the Contingency TAC (Tactical Air Command) Automated Planning System. Mission planners are then expected to adhere to assigned airspace corridor allocations. Procedural control mechanisms (the Air Tasking Order, ATO, and the Airspace Control Order, ACO) are used to allocate airspace to missions 1-3 days prior to mission execution. Modernization efforts seek to compress the deliberative planning cycle to the order of several hours. These efforts to compress the deliberative planning cycle do not address the timeliness of mission planning and airspace monitoring activities necessary to effectively support time-critical operations (e.g., on the order of minutes). The military services are actively engaged in exploring issues of engaging Time-Critical Targets (TCTs). There are issues in engaging TCTs that are not amenable to solution via simple compression of the deliberative planning cycle.

To effectively engage TCTs it is felt that airspace management that is primarily governed by assignment of air corridors is too restrictive. What is important for some air corridors in which missions are being flown is not avoidance of the air corridors by missions being dynamically planned to engage TCTs, but rather avoidance of the missions inside the corridors. The basic premise of the 4DD MOIE is that route-based airspace deconfliction or route conflict detection would provide more efficient use of airspace for the prosecution of TCTs. Such route-based conflict detection would also prove useful in deliberative planning cycles by allowing more flexible use of airspaces as well as providing mission planners information about other missions or activities that may be in proximity to their mission.

The basic approach of the 4DD MOIE was to explore the use of air traffic control concepts that are evolving in the FAA in situations of military mission planning and mission execution monitoring. MITRE's Center for Advanced Aviation System Development (CAASD) has been investigating the insertion of systems and technology to aid air traffic controllers. The culmination of one of its many areas of research is URET, the User Request Evaluation Tool. URET is a prototype that has evolved over more than 20 years of research and development in providing automation aids to air traffic controllers. URET provides Air Route Traffic Control Center (ARTCC) en-route air traffic controllers with a current air picture, displaying filed routes for aircraft in the ARTCC as well as current positions. It also builds trajectories for aircraft, which are projections based on aircraft models and routes and current information. A key feature of URET is that it provides controllers with an automated conflict probe capability to warn them of possible loss of minimum separation requirements in a window of time into the near future. Controllers can use URET to see upcoming conflicts between aircraft well before the conflicts become critical. URET can also be used to develop trial flight plan amendments and see if they resolve these upcoming conflicts. URET is being used in field evaluations in several ARTCCs. URET is being used for algorithm analysis and user interface requirements derivation, which will subsequently be used by an FAA contractor to build an operational system incorporating the main functions of URET.

URET was demonstrated at Fleet Battle Experiment-Bravo (FBE-B) at the end of summer 1997 aboard the USS Coronado. Reaction to the notion of route-based airspace deconfliction in support of military activities was positive. This provided the impetus to propose and fund the research and experimentation of four-dimensional airspace deconfliction under MITRE's Mission Oriented Investigation and Experimentation (MOIE) research program.

From its outset, the 4DD MOIE has had an affiliation with the PMA-281 Strike Cell. The PMA-281 Strike Cell is a Command and Control (C2) systems integration and experimentation laboratory funded by PMA-281, the U.S. Navy Cruise Missile Command and Control Program, and implemented at MITRE facilities in Reston, VA. The 4DD MOIE developed software prototypes to participate in a variety of Strike Cell demonstrations in FY99 and FY00. The 4DD prototypes were used to provide surrogate route mission planning capabilities and subsequently to demonstrate route-based conflict detection and visualization. The 4DD prototypes were also used as surrogate airspace monitoring and visualization stations until actual C2 systems providing Common Operation Picture (COP) support were integrated into the Strike Cell.

The 4DD MOIE has had several sponsors since its inception. PMA-281 acted as its initial sponsor. In FY00 the Joint Precision Strike Demonstration Office, which is the sponsor for the Joint Continuous Strike Environment (JCSE) Advanced Concept Technology Demonstration (ACTD), was asked to be the government sponsor for the 4DD research and development effort. JCSE has as a planned component an airspace deconfliction module. PMA-233 (Navy Mission Planning Systems) assumed sponsorship shortly after FY00 began, having expressed interest in the research as potential information support for its mission planners.

Section 2

Software Products of the 4DD MOIE

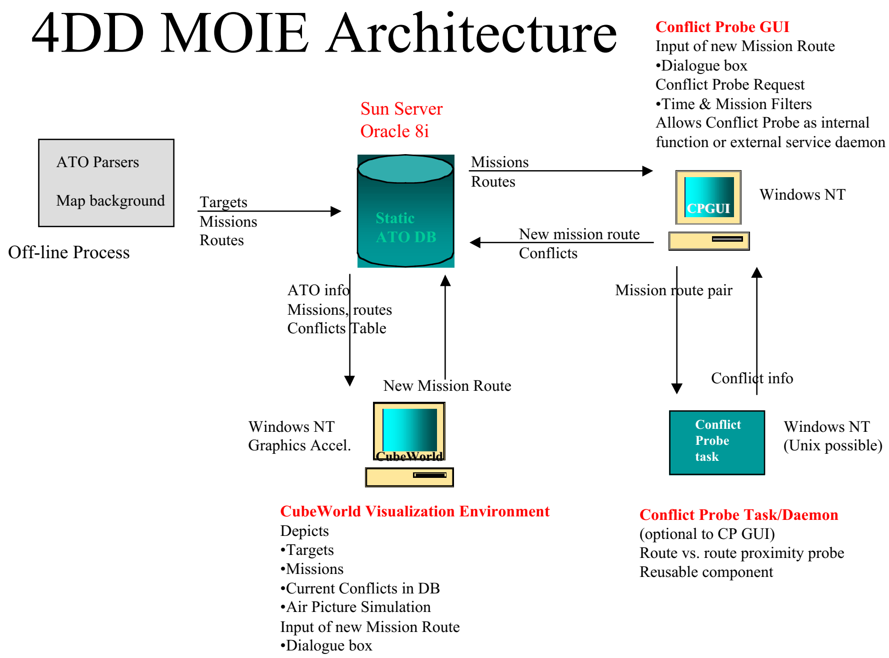
2.1 Prototyping Efforts

In FY99 the 4DD MOIE engaged in prototyping using a version of URET obtained from MITRE CAASD. Modifications were made to the graphical user interface (GUI) of URET to provide map outlines and icon placement capabilities that fit military engagement scenarios being explored in Strike Cell demonstrations. Extensive modifications involving flight plan creation and modification and flight plan insertions into the URET database and flight simulation for new flights were also made. Use of URET in the 4DD MOIE was halted because of the many legacy characteristics of URET and because of its inherent emphasis on civilian air traffic control. URET's legacy aspects and architectural features made it unlikely that it could be further evolved for use in military demonstrations, especially in demonstrations involving any kinds of interfaces with actual C2 systems.

In FY00 the 4DD MOIE adopted a software base from the Battlespace Visualization (BV) MITRE Sponsored Research (MSR) program. The BV software is called CubeWorld. It provided an environment for visualizing an ATO. Several of its primary features were that it had definite military scenario features, was developed using commercial database technology, and was developed using modern programming technology. Of greatest importance were the facts that as a MITRE product, the source code for CubeWorld and the development team were available to us. Our prototyping efforts included extensions to CubeWorld as well as development of a new component called the Conflict Probe (CP) GUI (CPGUI). The following provides an overview of the extensions developed:

- Airspace corridor visualization
- New route definition in CubeWorld (dialogue box interface, not point-and-click)
- Route conflict database query and conflict visualization in CubeWorld
- New mission route creation in the CPGUI (dialogue box interface, not point-and-click)
- Strike package, mission, and time filtering in the CPGUI
- Pop-up conflict report window in the CPGUI

The following figure depicts the general architecture of the 4DD prototype developed in FY00 that was based on the use of CubeWorld from the Battlespace Visualization MSR.



The software technologies used in the 4DD MOIE prototyping efforts in FY00 included the following:

- Unix and Windows NT development
- C, Visual C++, Java
- OpenGL
- Python Scripting Language
- Oracle 8i, SQL
- Java Data Base Connectivity (JDBC), Open Database Connectivity (ODBC)
- Extensible Markup Language (XML)

The following sections summarize the software products of the 4DD MOIE that are available for use after the MOIE's completion and discusses how they might be used in future CONOPS or requirements exploration or experimentation. The principal components of the 4DD prototype are CubeWorld, the CPGUI, the CP Daemon, and the database tables.

2.2 CubeWorld and CPGUI

CubeWorld in conjunction with the CPGUI are usable for off-line demonstrations of route-based conflict detection in support of dynamic strike mission route layout. They provide for a simple surrogate mission route planning capability as well as of a COP visualization and simple route-based conflict detection support. CubeWorld does not currently have robust ATO/ACO parsing or general map capabilities; off-line processes were used to build a database consisting of a single, static ATO, with table definitions inherited from the BV MSR.

2.3 CPGUI

The CPGUI is usable independent of the CubeWorld visualization environment. However, it would have to use the CubeWorld/4DD database tables.

The CPGUI component is usable for limited experimentation with existing C2 or mission planning systems in the following manner:

- CPGUI can be used to provide the ability to insert new mission information into the 4DD database. Mission and strike package identification must be distinct from any such identifiers in the static ATO in the database.
- CPGUI can then be used to invoke the conflict probe calculations with conflict reports provided in a pop-up dialogue box.
- An existing C2 or mission planning system could also populate part of the CubeWorld/4DD database tables directly by using SQL calls.
- Any visualization support would have to be provided by the C2 or mission planning system(s).

2.4 Conflict Probe Daemon

The conflict probe calculation can be run as a Windows task or a Unix daemon. It is callable by an external system, such as a C2 or mission planning system. There is an XML data interface description for the CP Daemon.

Database support, data formatting to call the CP daemon, and any report or visualization services would have to be developed for the C2 or mission planning system

Section 3

Lessons Learned on the 4DD MOIE

In our 2+ years of demonstrations to audiences with time-critical strike interests, we have had the opportunity to discuss CONOPS and airspace deconfliction issues with a number of parties. Our prototyping efforts have also given us some insight into development and insertion of 4DD capabilities into Navy and DoD C2 architectures. The following summarizes some of the major observations and lessons learned during the 4DD MOIE.

3.1 Use of URET in the Military

- **URET itself is not modifiable for use as a military system**

  URET possesses too many legacy characteristics, including substantial use of a legacy language (PL/I) and use of a legacy operating system (VMS). URET's conflict detection and trajectory modeling functions are very highly oriented toward civil air traffic control requirements, as are most of the other URET subsystems. Turning off or replacing civil airspace management features would be very costly. URET does not use commercial database technology. URET is very tightly coupled to ARTCC architecture, and it would be costly to modify it for general external data interfaces. The costs of such modifications would be too great to think it would be directly usable in military situations.

- **URET-like functions or systems might be useful for military activities near civil airspaces**

  Monitoring of civilian aircraft and maintenance of adequate separation from them could be useful during military exercises. Some future system(s) would have to provide such capabilities.

3.2 Requirements and CONOPS Observations

- **No Navy programs have been given the charter to define requirements for and assume responsibility for airspace deconfliction activities to support time-critical strikes**

  The JCSE ACTD had included in its design a component to provide airspace deconfliction support. However, at the time of this writing the JCSE airspace deconfliction module was behind schedule and there is not clear evidence that it will be completed.

The SPAWAR Systems Center in San Diego has led a project entitled Real-time Execution Decision Support (REDS). Navy program offices identified as stakeholders in REDS include PMA-281 and PMA-233. REDS functionality includes support for distributed mission planning, mission management and enhanced situational awareness, and tactical decision support for real-time retargeting. REDS has not identified airspace deconfliction as an activity supporting its dynamic mission replanning or mission management activities. REDS appears to be a desirable candidate to explore airspace deconfliction support for its primary activities.

- **The "big sky little bullet" philosophy is still prevalent**

  This may change when the sky becomes more full of unmanned surveillance and weapons platforms in conjunction with manned platforms and when sufficient network bandwidth and services are available to support dissemination of route information as part of the COP.

- **Route-based conflict detection support seems very applicable to mission planning**

  The use of route-based conflict detection would be very useful for mission planners as they plan a strike. At present the information about other missions that may be of interest to them is limited, for instance, to the planning group for a squadron. Having route information from geographically dispersed planners whose units will be working in the same vicinity would be useful. Route-based conflict detection support would also be useful in mission monitoring to provide alerts as to upcoming approaches of friendly aircraft of which the mission may not be aware.

- **Separation criteria for military situations would need to be developed**

  If route-based conflict probe evolves in military planning and monitoring then the separation criteria used by the conflict probe calculations would need to be developed. There are currently no requirements in this area. The FAA's use of separate vertical and horizontal separation requirements is too restrictive for military situations. In part, the military does not routinely fly missions at altitudes that are dependent on the direction of flight, which is why URET uses a two-part separation calculation. In military situations the use of separation criteria dependent upon platform and weapons classes may also be recommended. This requires additional requirements and CONOPS exploration.

- **Dissemination of route and mission information would require CONOPS exploration with regard to classification levels**

  Route information, and possibly platform information, for strikes would have to be disseminated to support route-based conflict detection support. Problems of need-to-know and classification levels would need to be addressed/resolved as part of CONOPS exploration and requirements development.

3.3 System Development or Modification

- **Development of a new Navy C2 system for airspace deconfliction is unlikely**

  It is unlikely that a new C2 system to introduce FAA-like airspace management capabilities into the military would be developed. The Navy and other services would probably be expected to supplement existing C2 systems by inserting new airspace deconfliction support into them. A likely candidate for adoption and further extensions is the Tactical Airspace Integration System (TAIS), which was developed for the Army. It possesses all of the necessary communications support to provide an overview of the airspace. It would require extensions to obtain route information and to incorporate conflict detection functions beyond its current checks of artillery fires against airspaces. Extensions to other systems to provide airspace deconfliction capabilities would require requirements and architectural analyses and further CONOPS exploration.

- **Issues of classification levels would have to be addressed by various systems receiving mission information**

  One of the major issues not addressed by the 4DD MOIE is that of classification levels. The 4DD MOIE assumed access to mission route information for all active missions. In reality, information about some missions may not be available or may require special security clearance levels. The issue of dissemination and use of mission information at various security levels by systems performing deconfliction services or using the information is one that would have to be addressed as part of requirements and CONOPS exploration and as part of the system development.

- **Information in the COP would have to include route information**

  If mission and airspace monitoring activities were to be extended to include route-based conflict detection, then information in the COP would have to be extended to include such route information. This also brings up issues of connectivity and network bandwidth availability that would have to be addressed.

- **Conflict probe in military use can probably be a simple proximity test**

  The conflict probe calculation used in URET was developed to take into account the FAA’s separation criteria of distinct horizontal and vertical separation amounts. These are applied taking into account that aircraft in en-route patterns are required to fly at specific altitude patterns dependent on general transit direction of the flight. The conflict probe calculation implemented in the 4DD MOIE prototype has vertical and horizontal separation criteria like that used in URET. Such requirements are not present in military mission route planning. Consequently, the conflict probe calculation in military situations could be a simple proximity test. However, the distances in many military instances might well be larger than in civilian instances.

- **Efforts to insert 4DD capabilities into existing C2 systems could be substantial, particularly for database access, network interfaces to other C2 systems, and user interface development**

  Database and remote system access, GUI development, and visualization support to portray conflict information could be extensive. Developments in such areas can be extensive even for simple capabilities; it is the nature of interface development. Any such development should be well analyzed for usability and effort.

- **Trajectory modeling in military conflict probe support can probably be simpler than in URET**

  URET's trajectory modeler is quite extensive, using aircraft profiles, route information, and recent vector history data. For military situations a much simpler approach could probably be used to provide a simple capability. For example, new trajectory information could be built by updating the time-on-station for waypoints in a route using a dead-reckoning approach. This is what the military simulation community uses in its distributed simulation/live participant architectures, with alerts for re-calibration only when an object has deviated significantly from its dead-reckoning projection.

Section 4

Possible Future 4DD Activities in Navy Programs

There are a number of possible activities that could be used to transition information and products from the 4DD MOIE to Navy programs and to further explore 4DD concepts within Navy programs. These activities fall into the following general categories:

- Use of the 4DD prototype for demonstrations
- Use of 4DD prototype components for limited experimentation with existing C2 or mission planning systems
- Requirements analysis, CONOPS exploration, architectural analysis with Navy program offices and their contractors

The 4DD prototype's software and hardware will remain in MITRE Reston facilities for any future demonstrations that Navy or other Service personnel may desire to see. These demonstrations can be used to illustrate the general concepts of route-based conflict detection support in mission planning and mission execution/airspace activity monitoring.

The 4DD prototype can be used to provide limited experimentation capabilities vis-à-vis route-based conflict probe to existing C2 and mission planning systems. The CPGUI and its conflict probe calculation can be used independently of the CubeWorld visualization environment. It can be used to insert new mission and route data into the 4DD database tables via its mission and route definition pop-up boxes. Alternately, an application could also make insertions into these tables with SQL update commands. The CPGUI could then be used to invoke the conflict probe calculations, with the user making certain that the filtering capabilities of the CPGUI are used to select appropriate missions for which the probes are meaningful. Some care would have to be taken to ensure easy identification of these new missions; mission and package identifiers would have to be chosen so that these new "local" missions, as they are called in the CPGUI, are distinct from those in the static ATO that the database holds. Additionally, accuracy of time-on-station and speed values would have to be verified manually, or at least verified externally to the CPGUI. One of the other difficulties in inserting new entries into the mission and waypoint tables of the 4DD database is that time in the tables is a relative time. The time in the tables was calculated for simulation purposes from the source ATO's time window. Any time values for new entries would have to be given in such a relative time, say time from start of ATO, and would have to fall within the same range as is currently in the database.

Another possibility in the area of experimentation with any existing C2 systems would be the use of only the CP daemon. It can be instantiated and called independently of the CPGUI. Its use would require the calling application to create a socket link to the CP daemon and pass it route-pair information in the expected formats. The calling application would receive a conflict report. The data interfaces are defined in XML. It would be up to the calling application to obtain the appropriate data, reformat it for presentation to the CP daemon, and to interpret the results and visualize them (if any visualization were to take place).

As mentioned in the section on lessons learned, there are no Navy programs that have in their charters the task of developing requirements and doing CONOPS exploration to support time-critical strike airspace deconfliction. It has been one of the hopes of the 4DD MOIE to influence appropriate Navy personnel to undertake such efforts. Given our experiences during demonstrations, scenario developments, and prototype development we could assist Navy personnel and Navy contractors in requirements development, CONOPS exploration, and architectural analyses with respect to introducing concepts of route-based conflict detection into military airspace deconfliction activities. At present the most likely candidates for transition of 4DD concepts are the JCSE ACTD and REDS. The latter would include participation of the tactical air (PMA-233) and possibly the cruise missile mission planning communities.