6 R&D PLAN TO SUPPORT DOMESTIC RADAR NETWORK DECISIONS

This chapter outlines an R&D plan of risk reduction activities to support a decision on how best to meet the Nation's future needs for surveillance radar. After the overview of goals and objectives in section 6.1, sections 6.2 through 6.4 present the three major components of the proposed R&D work:

- Technology development and testing;
- Proof of MPAR operational concepts; and
- Refinement of the MPAR network concept.

Section 6.5 summarizes the JAG's estimates of resources and schedule time required to conduct all the proposed activities in these three R&D components. Further details of the resource and schedule estimates are provided in appendix D.

6.1 R&D Strategy

6.1.1 Goal and Objectives

The goal of the proposed R&D strategy is to demonstrate that an affordable, high power, multipurpose phased array radar can be developed to provide the revolutionary capabilities described in chapters 3 and 4 of this report. The major objectives to be achieved by the proposed activities are:

- Technical risk reduction for the issues discussed in chapter 4;
- Establishment of a documented basis for cost comparisons between the MPAR and MRCR alternatives for meeting national domestic radar surveillance needs (building on the preliminary cost factor comparisons presented in chapter 5); and
- Formulation of the path forward for required research, development, test, and implementation, if an MPAR option for future surveillance is selected.

6.1.2 Leveraging Available Facilities and Ongoing Radar R&D Programs

To the extent possible, the R&D activities should leverage existing capabilities at Federal and university research laboratories and in industry. Ongoing weather radar R&D, specifically using the National Weather Radar Testbed (NWRT) and existing short-wavelength polarimetric radars, can be leveraged to substantial advantage. In the near-term, the NWRT will play a major role in activities such as testing scanning strategies, time management use for tracking aircraft and weather, and specialized signal processing and advances afforded by the agile beam. An X-band polarimetric radar that is already under development will be used to study short-wavelength radar units as potential low-level, short-range radars in a nationwide MPAR network. However, the most important aspects of multiple use coupled with digital beam forming will require developmental work using a prototype active phased array radar unit. This MPAR prototype will be developed as part of the Technology Development and Test component of the risk-reduction R&D plan.

Maximum use will be made of available and emerging military technology, as well as components used by the cellular telephone industry, by researching announcements of the latest developments and acquisitions in these fields. An up-to-date inventory of devices and developments will be maintained.

6.1.3 Provisional Concept for an MPAR Network

As a provisional concept for a nationwide, domestic radar network of MPAR units, the JAG/PARP envisions a scalable unit architecture used for both larger, long-range MPAR units and smaller units to provide low-level coverage, particularly near airports (Terminal MPARs). To improve coverage beyond that of existing systems and meet desired future capability, the network of these two MPAR sizes could be augmented with a dense network of boundary layer radars, as discussed in section 6.4.3.

Appendix B describes the provisional concept for long-range and Terminal MPAR units in detail. The risk-reduction R&D program will solidify requirements for units in this network—such as the component radar power-aperture configurations, waveforms, numbers of independent channels, numbers of concurrent beams per channel, and multifunctional tasking—in sufficient detail to define subsequent tasks and subsystem-level specifications, if a decision is made to pursue MPAR implementation.

- Scanning strategy options will be tested and assessed.
- Concepts will be tested with simulations in the laboratory and on the MPAR prototype.
- Comparative evaluations will be made of polarimetric operational performance at different wavelengths.

6.2 Technology Development and Test

Key engineering activities will include development and test of low-cost, critical component technologies such as T/R elements, analog and digital beamforming architectures, and efficient processing algorithms. A prototype MPAR unit will be developed and tested in an operational environment.

Chapter 5 describes the technology advances and capability requirements driving military and commercial sector progress in MPAR components and subsystems. Recent U.S. Navy programs have demonstrated the application of commercial packaging techniques to RF modules for high-performance phased array radars. The T/R Line Replaceable Unit (LRU) drives the performance, cost, and reliability of a solid-state antenna. Recent research has shown that reduction in T/R element and LRU costs can be achieved without sacrificing radar performance.

The proposed Technology Development and Test program combines these recent advances in solid-state technology with application know-how obtained from operating weather and air traffic control radars. Some aspects of the technology have been proven in other applications; other aspects require further development and testing. Whereas the core technology components of MPAR have been demonstrated in military applications, the scale and complexity necessary to support the multifunction capabilities described in chapter 4 will require concept verification and engineering test and evaluation. Another aspect that needs concept testing and refinement is the use of dual-polarization phased array antennas on a multiple-use radar unit.

Table 6-1 summarizes key parameters of the envisioned MPAR approach and indicates which parameters pose significant cost and technical development challenges. The most challenging are in red; the least challenging are in green.

TABLE 6-1. MPAR Key Technical Parameters*

🟥 **Total Number T/R-Elements per Radar**
🟨 **Number of Frequency Channels**
🟨 **Dual Polarization**
🟩 **Bandwidth (per channel)**
🟩 **T/R-Element Peak Power**
🟥 **Number of Concurrent Receive Beams**
🟥 **Software Complexity**
🟩 **Size, Weight Constraints**
🟩 **Prime Power Constraints**

** The background colors denote the level of technical and/or cost challenge imposed by each parameter. Red denotes substantial challenge, yellow denotes moderate challenge, and green denotes minimal challenge.*

To meet these challenges, the Technology Development and Test program includes the following tasks:

1. Reduce the cost of the T/R elements that provide the requisite power output and multichannel capability to well below $100 per element. To accomplish this reduction, leverage both DOD-sponsored development and commercial sector technology (e.g. the wireless telephone industry).

2. Assess the requirements for simultaneous (versus sequential-pulse) dual-polarization measurement capability. If the former is required, the impact on T/R-element cost and complexity must be quantified since this would essentially double the number of components (e.g. phase shifters, amplifiers) required per element.

3. Verify and validate the requirements for pulse bandwidth (for example, to support non-cooperative target length measurements or weather-radar "rapid scan" modes). Bandwidth requirements are an important factor in the cost of T/R elements, in downstream processing complexity, and in central processing unit requirements.

4. Demonstrate that highly digital array technology is affordable. For example, "overlapped sub-array" beamforming technology is an effective approach for generating the multiple concurrent receive beam clusters required to meet the time lines of the multiple surveillance functions. Significant opportunities exist to reduce the cost and complexity of sub-array beamformers.

5. Develop and demonstrate affordable transceivers that perform channel separation, down-conversion, and digitization for the T/R elements or sub-arrays in a modern phased array radar system.

6. Develop and demonstrate efficient, cost-effective processing architectures for the real-time beamformer. Multiple array outputs must be processed in parallel to form the large number of concurrent beams required to meet user needs. The associated processing load may be very large and will require careful design of both the processing algorithm and the processor configuration.

7. Conduct analyses to project radar cost trade-offs associated with operation in X-, C-, or S-band. Evaluate the capability of advanced processing algorithms and polarimetric measurement techniques that address performance issues at the different bands associated with sensitivity, ground-clutter suppression, range-Doppler ambiguities, and attenuation.

8. Evaluate alternative array geometries (e.g. planar, cylindrical, hemispherical), element grid geometries (e.g. rectangular, triangular), and "element-thinning" options.

9. Develop an MPAR prototype to provide an end-to-end demonstration that affordable, component technologies are realizable and that required multifunction surveillance capabilities can be realized at the projected level of performance. Field tests of this prototype will solidify key technical requirements such as number of independent channels and number of concurrent beams per channel.

10. Use the MPAR prototype to demonstrate the operational capability enhancements that can be realized through collaborative surveillance strategies that exploit the unique capabilities of a highly interconnected phased array radar network. Develop and test associated communications, control, and conflict resolution architectures. (This task dovetails with tasks to define the MPAR network concept. See section 6.4.2.)

11. Develop and test new aircraft surveillance post-processing techniques that exploit the unique capabilities of phased array radar to meet or exceed the performance of legacy air traffic control search radars. Consider at least the following capabilities: dedicated track modes, height resolution, non-cooperative target identification and integration with future cooperative target surveillance technologies such as ADS-B. (This task dovetails with late-stage tasks for proof of MPAR operational concepts. See section 6.3.4.)

12. Develop and demonstrate the unique capabilities and associated algorithm/system requirements for MPAR meteorological surveillance using the MPAR prototype.
    - Develop and demonstrate the use of MPAR in “warn on forecast” severe weather mitigation concepts and in improved aviation weather diagnosis and forecast services.
    - Develop common, scalable radar technologies that support long-range severe weather surveillance, hydrometeorological applications, and a dense network of boundary-layer radars.
    - This task dovetails with late-stage tasks for proof of MPAR operational concepts. See sections 6.3.1 and 6.3.3.

6.2.1 MPAR Component Technologies and Pre-Prototype Array

Tasks 1 through 5 in the preceding list, which demonstrate the cost reduction required in T/R elements having the requisite performance characteristics, are critical to the risk-reduction effort prior to a decision on the Nation’s next-generation radar surveillance systems. The T/R elements used for military system applications may not be appropriate, as military applications often require very high performance under difficult conditions (e.g., high output power under environmental extremes). Such systems must operate on military platforms that impose constraints on size, cooling, or prime power. Technologies developed for the commercial wireless industry may be exploited to provide the performance necessary for domestic MPAR units at much lower cost per T/R element. This task will thus require close collaboration with industry to develop and test affordable, prototype T/R elements with multichannel and dual-polarization capability. Bench tests on the power, efficiency, and polarimetric characteristics of candidate T/R elements and associated sub-array components will provide an early test of many of the assertions made in this report.

Demonstrations of low-cost module approaches, sub-array beamformers, and multi–channel transceivers are needed to validate their ability to support the performance goals of MPAR. To conduct these demonstrations, a fractional array consisting of a few hundred T/R elements and comprising an aperture several square meters in area will be developed. The array will support two to three concurrent frequency channels, with 5 to 10 simultaneous receive beams per channel. Development and test of this small-scale, “pre-prototype” PAR antenna will enable exploration and resolution of key technical issues, while demonstrating whether the core technologies underlying the envisioned MPAR approach are viable and sufficiently robust. Figure 6-1 illustrates a possible physical implementation of this pre-prototype antenna, which could share most of its components (pedestal, processor, and display) with the existing NWRT.

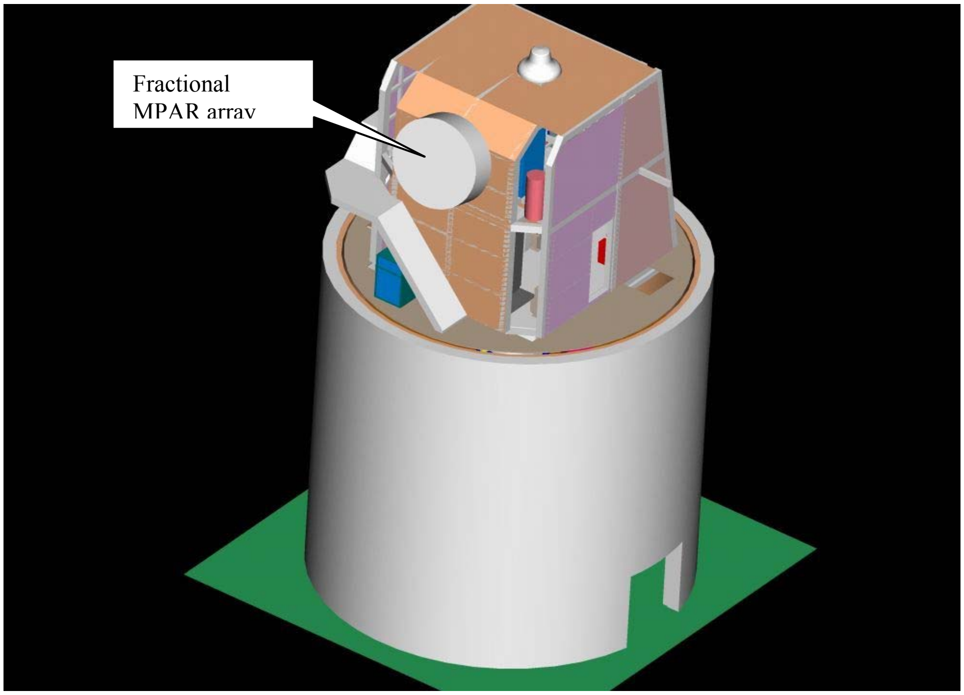

Figure 6-1. Artist's concept of a fractional MPAR array mounted on the backside of the current NWRT frame.

6.2.2 Full MPAR Prototype

Tasks 9 through 12 in the list of Technology Development and Test activities pertain to a "full-up" MPAR prototype unit. Subsystem-level technology development and small array testing in the 2006–2009 time frame (tasks 1 through 8) will set the stage for development of this prototype MPAR unit. The prototype, which will be developed in collaboration with industry, should be capable of providing the full range of operational services described in this report. A multiyear technical and operational test program will be conducted to establish that all key user needs are satisfied and that MPAR is economically and logistically viable.

6.3 Proof of MPAR Operational Concepts

The second component of the MPAR risk-reduction R&D plan encompasses a set of proof-of-concept experiments. Early-stage, proof-of-concept experiments can be conducted on the NWRT. Late-stage experiments will require use of the MPAR prototype described above. Others will be stand-alone evaluations, and some will be software procedures.

Early-stage experiments, conducted in parallel with tasks 1 though 8 in the Technology Demonstration and Test component, will use the existing NWRT in Norman, Oklahoma, and existing shorter-wavelength radars. These assets will be used to collect appropriate data to test, validate, and refine key operational concepts for a nationwide MPAR network, including severe weather "warn on forecast" capabilities, simultaneous surveillance of weather and aircraft, and evaluation of short wavelength (C-band and X-band) technology and phenomenology as applied to the preliminary Terminal MPAR concept for low-level, smaller units in the MPAR network. An early goal of the risk-reduction program will be to demonstrate that MPAR units can meet or exceed the capabilities of the systems they would replace. The specification for each system to be replaced will be the basis for these comparisons, which will form a crucial and integral part of the test plan and objectives.

6.3.1 Signal Design for Weather Monitoring

Two major complementary technological developments make rapid acquisition of weather radar data possible. These are transmission and processing of wide bandwidth signals and beam agility of an active phased array radar. Both will be tested on the NWRT and the prototype MPAR unit. With beam agility and adaptive scans, the existing NWRT phased array radar should achieve a twofold to fourfold decrease in the time required for a full-volume scan. A five- to ten-fold decrease in full-volume scan time will require simultaneous scanning from multiple antenna faces, combined with advanced signal designs and processing. These capabilities can be demonstrated on the MPAR prototype.

Oversampling and decorrelation of signals in range is a candidate signal processing technique that will be tested. This technique is effective at large signal-to-noise ratios and has been accepted as an improvement for the existing WSR-88D units. Testing can start in the near future, as this capability is built into the NWRT and the provision exists to record time-series data. The MPAR prototype, when developed, will provide further capabilities that support rapid data access, specifically the capability to process in parallel multiple radials of received data from a target that has been illuminated simultaneously by a broader transmit beam.

6.3.2 Beamforming and Processing

Concept definition studies and subsequent prototype testing will define the number of concurrent beam modes needed for MPAR units in the envisioned network and the functionality of each beam mode. For example, a fan beam similar to that produced by the current ASRs could be transmitted. The digital beamformer on receive could be programmed to focus simultaneously in a pencil-beam fashion at all the elevations illuminated by the transmit beam. Other possibilities for wideband illumination and pencil-beam reception will be explored. A common feature of these options is that multiple array outputs must be processed in parallel to form the required number of concurrent beams. Substantial theoretical study will be followed by careful design of both processing algorithms and processor configuration.

6.3.3 Weather Processing Algorithms

A key feature of an electronically steerable phased array radar beam is that it can be used to obtain volumetric data with variable spatial and temporal resolutions. Because positioning of the beam has no associated mechanical inertia, the beam can be moved nearly instantaneously in arbitrary directions. Thus, a target volume of interest can be covered by a constellation of data samples of differing data density, similar to the differences in density that occur in a three-dimensional wedge of fruitcake. Certain regions in the target volume can be represented by high-resolution data, while regions of lesser interest are represented by a relative paucity of reflection data.

These adaptive volume coverage patterns can be developed and tested initially on the NWRT. Adjustments of the standard weather processing algorithms can be made to adapt them to the phased array radar environment. The best way to make these adjustments to exploit the unique features of phased array radar will be determined. Moreover, the variable resolution of phased array meteorological radar data presents new and exciting challenges for display and visualization in both research and operational applications. Important early work in this area can be accomplished on the NWRT or using NWRT data sets.

6.3.4 Aircraft Processing Algorithms

Early demonstrations of multifunction capability will use the single, electronically scanned agile beam of the NWRT. Although full-capability non-cooperative aircraft surveillance will require dedicated frequency channels and multiple, concurrent receive beams, as described in chapter 4, early proof-of-concept demonstrations with the NWRT will be useful. Significant effort is needed to develop and demonstrate efficient multipurpose use, but these studies can be accomplished with the existing NWRT in Norman.

As explained in section 2.2, the FAA's NGATS plan emphasizes cooperative surveillance technologies such as ADS-B for air traffic control services. Nevertheless, a complementary non-cooperative target tracking capability is required in the event of equipment failure, GPS signal jamming, or intentional spoofing. MPAR is one option for providing this complementary capability, but a detailed understanding of the role of complementary tracking capability in the future air traffic control system should be developed.

Once the MPAR prototype is developed, it can be used to refine and demonstrate non-cooperative aircraft surveillance capabilities. MPAR's capability for height resolution and dedicated track modes is expected to provide significant reductions in false-track occurrence and should provide more accurate estimates of target location and track velocity. This part of the risk-reduction plan is intended to assess the impact of these enhanced capabilities on air traffic control procedures and non-cooperative target threat assessment.

6.4 Refinement of the MPAR Network Concept

The network concept presented in appendix B will require further validation and refinement. Many of its assumptions can be tested through the first two components of the proposed MPAR risk-reduction R&D program. Prior to a commitment to network acquisition, however, there are two network-level confirmatory studies that the JAG/PARP considers essential to validating and refining its preliminary network concept. One study will test the option of using shorter-wavelength radars for the Terminal MPAR units in an MPAR network. The second will explore and test strategies for collaborative surveillance of the same target by several units in the network.

6.4.1 Short-Wavelength Terminal MPAR

The provisional concept for a national network of MPAR units includes smaller, lower-cost radars, to provide a denser network that extends radar coverage closer to the ground at strategically important locations such as airports (appendix B). These Terminal MPAR units would be less expensive versions of the main MPAR unit design, hence the risk-reduction R&D in the Technology Development and Test tasks will be directly applicable to them as well.

For reasons explained in appendix B, it may prove advantageous to operate the Terminal MPAR units at shorter wavelengths than are used for the main MPAR units. Therefore, a network-related study is proposed that would evaluate the utility of C-band (5 cm) and X-band (3 cm) polarimetric radars in the Terminal MPAR role. The initial part of this study can use existing MRCR units operating at these wavelengths. Tests of polarimetric capability at C band wavelengths will be made after adding polarization diversity to existing mobile MRCR units. Similarly, testing of polarimetric capability at X-band wavelengths will be made using a research radar that is currently being developed. The study will capitalize on data from other sources, including private firms and foreign weather services.

6.4.2 Collaborative Surveillance Strategies

Throughout the MPAR risk-reduction R&D program, consideration should be given to operational enhancements that can be achieved with surveillance strategies that make use of collaboration among radar units in the MPAR network. Collaborative surveillance strategies are already being investigated for some of the legacy radar systems, such as collaborations involving WSR-88D units, TDWR units, and the weather data component of ASR units. For this element of the MPAR risk-reduction program, data collected with the NWRT can be combined with the collaborative data from these legacy radar types. Additional conceptual studies for the design and simulation of surveillance strategies will be used to seek collaborative strategies that best exploit the advanced capabilities of a highly interconnected phased array radar network. For example, a proof-of-concept Terminal MPAR prototype will be used in experiments on complementary (and somewhat overlapping) scanning and data collection employing both sizes of the MPAR unit.

6.4.3 Network Coverage for Aircraft Surveillance at Low Elevations

The provisional concept for a nationwide MPAR network described in appendices B and C includes larger, long-range MPAR units and smaller Terminal MPAR units. Such a network would give 90 to 95 percent coverage of the National airspace at 5,000 ft. elevation and above, and probably about 55 percent coverage from 5,000 ft. down to 1,000 ft. This coverage is at least equivalent to that of existing air surveillance networks. The long-range MPARs and Terminal MPARs would use a scalable unit architecture for efficiencies in acquisition and savings in both acquisition costs and total life-cycle costs.

As table 2-2 shows, the desired future capability for aircraft surveillance is total coverage of the National airspace from the surface to an elevation of 100,000 ft. One option to explore for increasing coverage at lower elevations is the addition of a dense network of low-level, atmospheric boundary-layer radars to augment the long-range and Terminal MPAR units. Such radars could be similar in design to the CASA (Collaborative Adaptive Sensing of the Atmosphere) radars, which are being developed for comprehensive sampling of the boundary layer. As noted in section 4.1, development of a scalable active array architecture could provide a common technology base for all three phased array radars: long-range MPARs, Terminal MPARs, and low-level boundary-layer radars. Technical and cost trades to achieve various levels of coverage approaching the ideal of "surface to 100,000 ft. everywhere" coverage will be explored. Coordination and collaboration with the CASA program will be essential to this part of the risk reduction program. However, neither the current CASA program objectives nor the CASA cost structure is reflected in the technical and cost estimates in this report.

6.5 Time Line and Resource Estimate

This section presents high-level milestones and costs for the three components of the MPAR risk-reduction R&D program. The plan for the 2006–2007 time frame includes parallel paths for tasks 1 and 2 in the Technology Development and Test program: addressing the key cost drivers for an MPAR unit, the multichannel T/R elements, and the overlapped sub-array beamformer. Industry contracts will be awarded to implement previously demonstrated, low-risk designs for these subsystems. Innovative designs of "ultra low cost" subsystems will be developed, implemented, and tested. The JAG/PARP expects that these designs can reduce the costs of key MPAR subsystems by a factor of 10. A comparative performance and cost evaluation will be conducted to determine which subsystem design should carry forward into follow-on development and test activities for the full-up MPAR prototype.

Figure 6-2 shows a time line and cost for the three major program components discussed above: MPAR technology development and test, proof of MPAR operational concepts, and refinement of the MPAR network concept. Appendix D contains a detailed breakout of tasks, including task definitions, for each program component.

	Year	2007	2008	2009	2010	2011	2012	2013	2014	2015
MPAR ops concepts ($52M)	Signal Processing Scan/Weather Obs.	6								
	A/C track/weather observations-Des/Bld DP Subarray		6							
	A/C track/Dual Pol Subarray test			11	11	6				
	Operational App						6	6		
Tech dev. and test ($158M)	Concept Study/pre-proto array	3	7	8	10					
	PAR Des/Fab/test/OT&E					29	33	29	29	
	Operation Test and Demo, Technology Transfer									10
Refine MPAR network concept ($5M)	X/C band tests	1								
	Architecture/subsystem Des.&Dev.		1							
	Proof of Concept			1	1	1				
Annual totals ($215M)		**10**	**14**	**20**	**22**	**36**	**39**	**35**	**29**	**10**

Figure 6-2. MPAR risk-reduction R&D program schedule.
Numbers in the schedule blocks are the planned FY costs per year in millions of dollars.