To Improve the Azimuth Resolution in Ground Mapping Radar using Doppler Beam Sharpening Technique

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Abstract*-Airborne radars are used to provide high-resolution ground mapping. Basically, the ground mapping is done using real beam ground mapping. The problem with real-beam mapping is the relatively poor resolution provided by the radar antenna. To improve the resolution in ground mapping, the next stage of mapping i.e. Synthetic Aperture Radar (SAR) mapping has been employed. Due to some limitations with SAR mapping, there is some reduction with the azimuth resolution. Doppler beam sharpening (DBS) is a next stage and is an effective method to improve the azimuth resolution of airborne pulse Doppler radar in its air-to-ground mode. In this paper, DBS method is implemented to enhance azimuth resolution from the moving platform (aircraft) by discriminating the different Doppler shifts from stationary targets at different angles with respect to the direction of motion. In the present study, we assumed required parameters and calculated Pulse Repetition Frequency (PRF) and scan speed for the pulse transmission. By finding the Inphase data and Quadrature data we plot the image taking absolute value of IQ data array. We develop an algorithm for Doppler beam sharpening for different azimuth angles of target and finally obtain fine azimuth resolution. We have done Coding and Simulation using MATLAB

***Keywords*- Ground mapping, azimuth resolution, pulse compression technique, pulse Doppler radar, Doppler frequencies.**

I.INTRODUCTION

Radar equipments are carried by commercial and military aircraft. These aircraft use airborne radar systems to assist in weather assessment and navigation. Military systems also provide other specialized capabilities such as targeting of hostile aircraft for air-to-air combat, detection and tracking of moving ground targets, targeting of ground targets for bombing missions, and very accurate terrain measurements for assisting in low-altitude flights. Airborne radars are also used to map and monitor the Earth's surface for environmental and topological study [1].

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Airborne radars are used effectively to provide high-resolution mapping [1] of Earth's (or other planetary) surface, with a technique called Synthetic Aperture Radar (SAR) [1][6]. The processing uses the fact that surface objects reduce the Doppler Shift [1][3][5] (due to the aircraft's flight) unique to their position as the aircraft passes by; this Doppler history is indicative of the scatterer's lateral, or azimuth(cross-range), position at the particular range determined by the mutual echo timing. With very sable radars and well measured flight characteristics (and other focusing methods), picture cells (pixels) of 1 ft x 1 ft (0.3m x 0.3m) can be formed in the processed images from radars tens of hundreds of miles away. The resolution [3] is somewhat like that possible, had the flight path itself been used as an antenna, the synthetic aperture.

Airborne radars present unique design challenges, mainly in the severe nature of the ground echo received by the radar and in the installation constrain on the size of the radar. The peculiar clutter [1][2] situation governs the nature of the signal processing, and the installation limitations influence the antenna design and the radio frequency to be used as well as the packaging of the rest of the radar. Similar considerations influence the design of space-based radars as well.

The radio waves transmitted by radar are scattered back in the direction of the radar in different amounts by different objects—little from smooth surfaces such as lakes and roads, more from farm lands and brush, and heavily from most man-made structures. Thus, by displaying the differences in the intensities of the received echoes when the antenna beam is swept across the ground, it is possible to produce a pictorial map of the terrain, called a ground map.

The degree of detail provided by radar map depends upon the ability of the radar to separate (resolve) closely spaced objects in range and azimuth. Range resolution is limited primarily by the width of the radar's pulses. By transmitting wide pulses and employing large amounts of pulse compression, the radar may obtain strong returns even from very long ranges and achieve range resolution as fine as a foot or so.

II.REAL-BEAM MAPPING

The simplest method of radar ground mapping is known as real-beam mapping. Widely available on fighter radars for many decades, it uses the main beam of the antenna to scan the terrain ahead of the aircraft. Real-beam mapping technique generates the most basic radar map that can be obtain from a radar mounted on either a stationary or a moving platform. The size of the cells varies with range and usually the down-range resolution is far higher than the cross- range resolution. For example, radar operating with 5 MHz bandwidth has a range resolution of about 30m. If it has a 3° beamwidth the cross range resolution at 20 km range is about 1000m. Hence, the down- range resolution is about two orders of magnitude higher than the azimuth resolution.

In real beam ground mapping, azimuth resolution is determined by the width of the antenna beam (Fig 1)

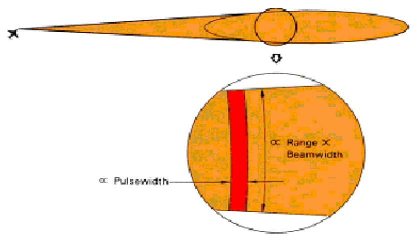

Fig 1 With real beam mapping, dimensions of resolution cell are determined by pulse width and width of the antenna beam.

The problem with real-beam mapping is the relatively poor resolution provided by a radar antenna. In a typical fighter radar of around 40cm diameter, the antenna beam width is around four degrees. The azimuth resolution available from such a beam is dependent on range, increasing with distance. At best, it will be measured in hundreds of meters, at worst in kilometers. The resulting crude imagery limited the usefulness of radar ground-mapping modes. Although useful as a navigation aid, it is unable to show individual targets.

Azimuth resolution may be improved by operating at higher frequencies or by making the antenna larger. But if exceptionally high frequencies are used, detection ranges are reduced by atmospheric attenuation, and there are practical limitations on how large an antenna most aircraft can accommodate. However, an antenna of almost any length can by synthesized with a technique called synthetic array radar (or synthetic aperture radar), SAR.

III. SYNTHETIC APERTURE RADAR

Synthetic-aperture radars (SAR) were developed as a means of overcoming the limitations of ream aperture radars. Synthetic aperture radar is a technique for taking extremely high resolution radar images, typically of ground features from an airplane. In Synthetic aperture radar (SAR) the large, highly-directional rotating antenna used by conventional radar is replaced with many low-directivity small stationary antennas scattered over some area near or around the target area. The many echo waveforms received at the different antenna positions are post-processed to resolve the target.SAR has seen wide applications in remote sensing and mapping.

If the antenna used for SAR is pointed not at right angles to the line of flight, but at some intermediate angle between 90 degrees and the line of flight, SAR techniques will still provide an improvement in resolution that will be useful for ground-mapping purposes. Since the SAR technique relies on the radial velocity of the ground relative to the radar-equipped aircraft, this resolution will decrease as the antenna angle moves towards the direction of flight.

To overcome, the limitation of SAR for improving azimuth resolution in ground mapping, Doppler Beam Sharpening (DBS) method is introduced. In the present study there is a detail explanation on Doppler Beam Sharpening (DBS) method for improving azimuth resolution.

IV. DOPPLER BEAM SHARPENING (DBS)

Doppler beam sharpening (DBS) is the next stage towards providing higher cross- range resolution. This technique is employed in airborne and sometimes spaceborne radars to provide higher resolution maps of the terrain that can be achieve by using the cross- range resolution available from the antenna beam width alone. The increase in cross- range resolution achieved is dependent upon the differential Doppler velocities that can be instantaneously measured.

Modern fighters always take up multiple missions on the battlefield, such as scout, air-to-air interception and air-to-ground attack. Thus, it is required that airborne radar should have simultaneous air-to-air mode and air-to-ground mode capability. Considering the limitation of the carrying capacity in the head of the fighter, pulse Doppler (PD) radar is usually used. The PD radar can suppress the strong background clutter with the technique of Doppler spectrum separation. The high resolution in the range direction can be realized by pulse compression. However, it is more difficult to achieve high resolution in the azimuth direction. In 1951, C. Wiley proposed the principle of DBS, and the first unfocused radar image was produced in 1953. From that time the technique of DBS developed quickly. Currently, new PD radars, whose Doppler sharpening ratio can reach 128:1, have been put into practice. In China, DBS research has been in development for more than fifteen years, and has produced numerous papers

V. PRINCIPLE OF DBS

DBS can be regarded as a certain mode of SAR. The angles between the targets located in different azimuth directions and the aircraft flight course are different from one another. Thus, the radial velocities of the targets locating in different azimuth directions are also different from one another. Therefore, different Doppler frequencies are induced. If a set of narrow band filters are placed in the frequency-domain, whose center frequency is aimed at the centroid of Doppler spectrum in azimuth direction, and whose bandwidth covers the Doppler frequencies induced by all targets, targets located in different azimuth directions can be distinguished. Therefore, high resolution is achieved in the azimuth direction.

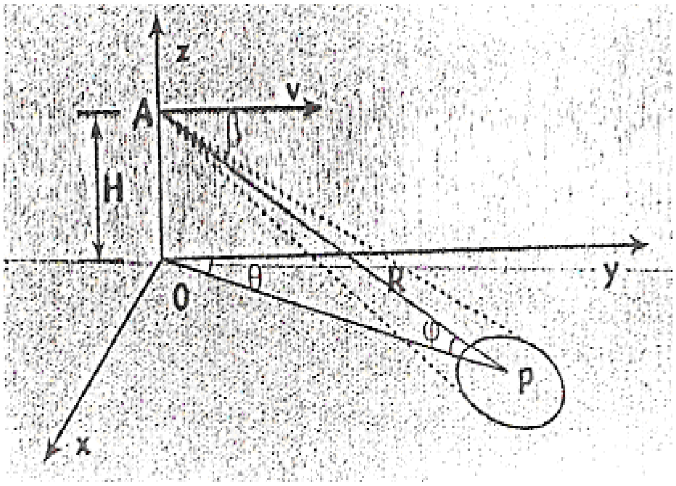

Fig 2.The geometry of the radar and ground target.

Fig 2 is the geometry of the ground target and airborne radar. The aircraft A, whose flight height is H, moves along the Y-axis at a uniform speed v. The azimuth and elevation angles of the PD radar mainlobe are θ and Φ, respectively. The intersection between the centerline of mainlobe and the ground is P. The slant range between radar and point P is R. The antenna -3 dB beamwidth is β and its wavelength is λ. The Doppler frequency induced by the target which is located on point P is

$$f_{d0} = 2*(v/\lambda) \cos\theta \cos\Phi$$

There are scatterers located in the same range gate R that have the same elevation angle. However, their azimuth positions are different. That is to say, they have different Doppler shift. The Doppler bandwidth in the mainlobe irradiating area is

$$\Delta f_d = f_{dmax} - f_{dmin} = 2*(v/\lambda) \cos(\theta-\beta/2) \cos\Phi - 2*(v/\lambda) \cos(\theta+\beta/2) \cos\Phi$$

Considering that β is very small, the Doppler bandwidth Δfd can be approximated to

$$\Delta f_d = 2*(v/\lambda)\, \beta \sin\theta \cos\Phi$$

To sharpen the antenna's -3 dB mainlobe, the Doppler bandwidth Δf_d should be divided. If the sharpening ratio is N, N narrowband filters should be used to divide Δf_d as shown in Figure 3.

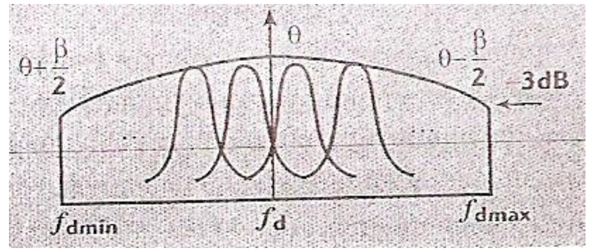

Fig 3.The division of azimuth Doppler bandwidth

In practice, N narrowband filters can be implemented by an N-point fast Fourier transform (FFT) operation. The radar PRF is set to correspond to the Doppler bandwidth Δf_d and f_{d0} induced by the target located in the centerline of the mainlobe should be set to a position of PRF/2. When N pulses are received by the PD radar at the frequency of PRF, N-point FFT forms N narrowband filters in the frequency-domain. Therefore the targets locating in the mainlobe can be distinguished in azimuth.

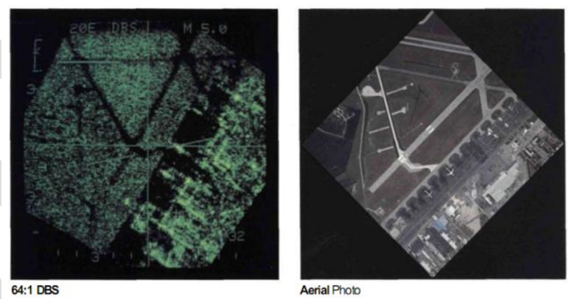

Fig 4. Image using DBS method

VI. DBS PARAMETERS

Table:1 DBS PARAMETERS FOR PRESENT STUDY

Number of range bins to be processed	500
Carrier Frequency (f_c) in Hertz	10Ghz
Speed of light (c) in meter	$3*10^8$ m/s
Beam sharpening ratio (γ)	64
Velocity of Aircraft in meter/s (v)	100 m/s
Beam width in degree (β)	3°
The number of beams to be processed	15
Range resolution	2 m
Azimuth resolution	2 m
Amplitude of received echo	5
Antenna movement	1.5°
Starting angle of scan	15°
Azimuth angle (θ)	15° to 60°
Number of FFT points	4096

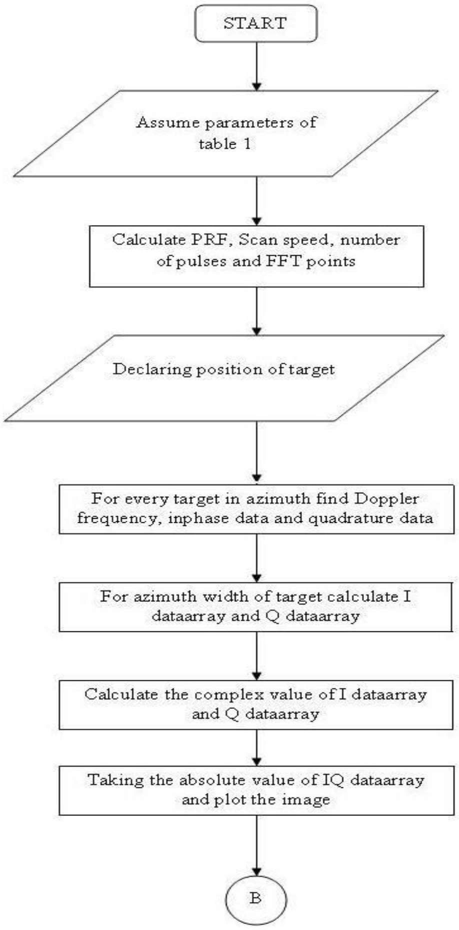

Fig 5. Flow chart to generate DBS raw data for each azimuth target

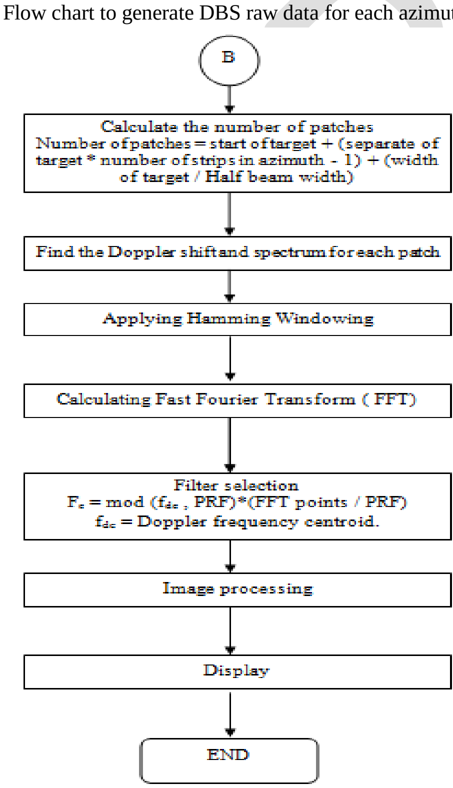

Fig 6. DBS processing algorithms on simulated raw data to verify the functionalities of algorithms.

VII. DBS ALGORITHMS

A. Motion Compensation

Ideally the aircraft maintains uniform linear motion in the DBS mode, and its posture also is constant. When the aircraft carries out a maneuvering motion, the DBS algorithm will be invalid. In addition, PD radars are usually installed in fighters. Even though the fighter does not engage in a maneuvering motion, it may deflect the ideal uniform linear motion due to disturbance of the atmosphere. The compensation for maneuvering can also be divided into two parts. The first one is posture compensation, which can compensate all posture changes of the aircraft, such as pitching, rolling and yawing, to correct the beam boresight to aim at the center of the imaging area. The second one is flight course compensation, to compensate for the variation of range between the radar and scatters for the deflection of an ideal flight course. The above two compensations are based on the airborne INU system.

B. Windowing

Windowing is a technique used to shape the time portion of your measurement data, to minimize edge effects that result in spectral leakage in the FFT spectrum. By using Window Functions correctly, the spectral resolution of your frequency-domain result will increase. SAR usually apply FM signals to resolve nearly placed targets and improve SNR. Main drawbacks in the pulse compression of FM radar signal that it can add the range side lobes in reflectivity measurements. Using weighting window processing in time domain it is possible to decrease significantly the side lobe level of output radar signal that permits to resolve small or low power targets those are masked by powerful ones. There are usually used classical windows such as Hamming, Hanning, Blackman-Harris, Kaiser-Bessel, Dolph-Chebyshev, Gauss, etc in window processing.

C. Fast Fourier Transform (FFT)

There are several ways to calculate the Discrete Fourier Transform (DFT), such as solving simultaneous linear equations or the correlation method.

The Fast Fourier Transform (FFT) is another method for calculating the DFT. While it produces the same result as the other approaches, it is incredibly more efficient, often reducing the computation time by hundreds. This is the same improvement as flying in a jet aircraft versus walking! If the FFT were not available, many of the techniques would not be practical. While the FFT only requires a few dozen lines of code, it is one of the most complicated algorithms in DSP

D. Filters

Although multi-look processing reduces radar speckle, it does not eliminate it. The remaining speckle noise can be further reduced by applying a spatial filter to the image. Unlike the additive noise found in many images, radar speckle is approximately multiplicative. Using this mathematical model, a measure of the noise range (standard deviation) can be estimated from the actual brightness variations in the image, using either the local neighborhood of the filter window or the entire image. The radar filters (Sigma, Frost, Lee, and Kuan) use these noise estimates in various ways to control the filter process. The objective is to reduce the speckle noise in uniform regions by some type of averaging while preserving the brightness variations that occur at the boundaries between areas of differing overall brightness.

Application of the radar filters can reduce but not eliminate speckle noise. Several applications of one or more filters may be required to reduce speckle to an acceptable level. However, each application of a filter results in some blurring, or loss of spatial detail. You will need to determine the balance between noise reduction and loss of spatial resolution that is appropriate for your radar images and interpretation objectives.

E. Imaging

For an imaging radar system, about 1500 high- power pulses per second are transmitted toward the target or imaging area, with each pulse having a pulse duration *(pulse width)* of typically 10-50 microseconds (us)

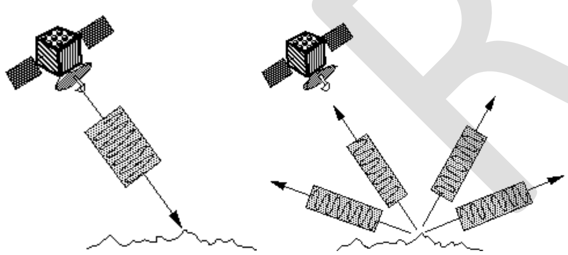

Fig 7. Radar transmits a pulse Measures reflected echo (backscatter)

At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some reflected back toward the antenna. This backscatter returns to the radar as a weaker radar echo and is received by the antenna in a specific polarization (horizontal or vertical, not necessarily the same as the transmitted pulse). These echoes are converted to digital data and passed to a data recorder for later processing and display as an image.

VIII. EXPERIMENTS AND RESULTS

As stated previously, Doppler Beam Sharpening (DBS) method is used to improve the azimuth resolution. Simulation is done using a tool called MATLAB and all the coding is done using MATLAB.

This can be shown by taking 500 numbers of range bins in x-axis and Pulse Repetition Time (PRT) i.e, time interval between transmissions of pulses is taken in y-axis. Assume the number of targets in both azimuth and range.

Figure simulated cross test object (raw data) after applying Doppler Beam Sharpening (DBS) method.

Figure 8 shows the simulated cross test object (raw data) before applying Doppler Beam Sharpening (DBS) method with 2 azimuth targets and 4 range targets. Figure 9 shows the Simulated cross test object (Raw Data) after applying Doppler Beam Sharpening (DBS) method. So with the beam sharpening ratio of 64 in Figure 9 all targets are visible with fine resolution.

Similarly Consider there are 5 targets in range and 6 targets in azimuth. Figure 10 shows the simulated cross test object (raw data) before applying Doppler Beam Sharpening (DBS) method; figure 11 shows after applying Doppler Beam Sharpening (DBS) method Comparing all the figures we can find the position of the targets accurately with the beam sharpening ratio of 64 and also with higher resolution. So by knowing the exact location of the target with high resolution we can distinguish terrain features and can recognize and identify selected man made targets. Modern fighters which take up multiple missions on the battlefield, such as scout, air-to-air interception and air-to-ground attack makes use of Doppler Beam Sharpening (DBS) method of ground mapping.

A. Simulated Results

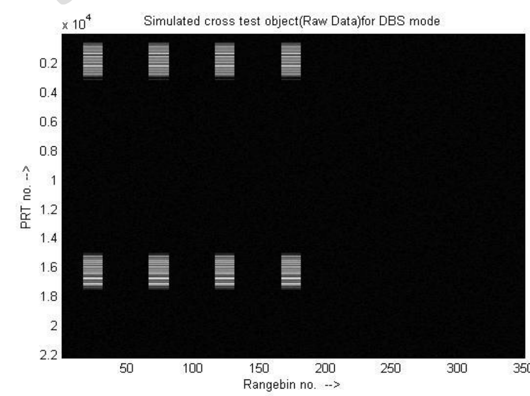

Fig 8. Before DBS

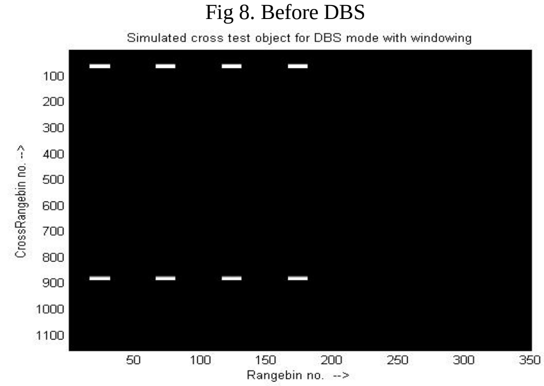

Fig 9. After DBS

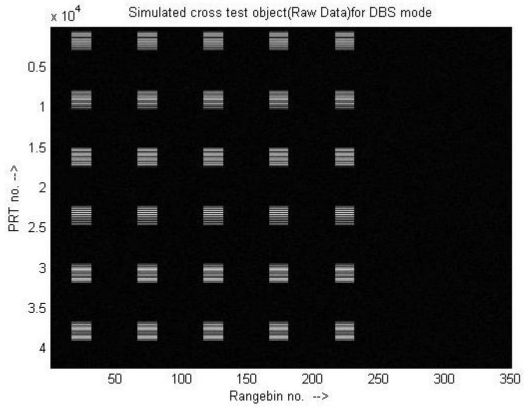

Fig 10. Before DBS

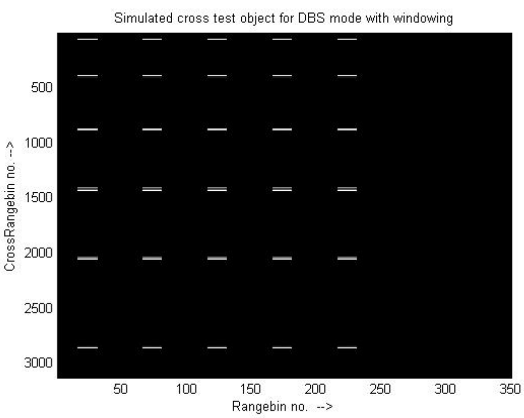

Fig 11. After DBS

IX. CONCLUSION AND FUTURE WORKS

Doppler beam sharpening high-resolution mode enhances situational awareness and aids in target recognition. DBS gives an accurate map of a selected area with an 8:1 azimuth resolution improvement. A resolution of 64:1 is possible with DBS mode. This mode will give future off-boresight weapons the improved resolution needed for precise launch data.

Future works will be focused on increasing beam sharpening ratio and the velocity of the aircraft to obtain azimuth resolution in ground mapping radar.

Doppler radar system which makes use of Doppler beam-sharpening has potential as the basis for a collision avoidance system in aerial vehicles and further work on the concept is certainly justified.

Future navy guided weapons require increased capability to attack moving and stationary targets in all weather and environment conditions. New inventions and technologies for seekers that will significantly improve the capabilities of existing weapon systems. These are essential to enable future weapon systems to maintain battle space superiority.

. ACKNOWLEDGMENT

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