SPECULATIVE ANALYSIS OF RMA VELOCITY
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Introduction

This project is a speculative analysis of what factors affect the speed with which RMAs are adopted. It draws upon past research into RMAs to identify the factors that affect their speed and then looks at three RMAs in the interwar period to examine how those factors appeared. Then it asks how fast RMAs have been occurring in the past several decades and whether the factors that affect that speed are significantly different from those in effect in the interwar period. Finally, it asks how these current RMAs might have progressed more rapidly, and thus what might be steps to take in the future to affect the speed of an RMA.

This is a speculative analysis. The scale of the project does not permit a detailed analysis of a large sample of RMAs, the development of a standard set of data and building set of hypotheses to be tested through the data. Rather, this study is largely an analysis of the research of others, and the development of a set of possible characteristics which those studies suggest affect the rate of progress in an RMA.[1]

This analysis does not attempt to resolve differences of views between analysts on the general subject of RMA. Analysts universally accept that periods occur in which substantial changes take place in the manner in which war is fought, and that technologies, force design, and force operational practices are instrumental elements in those changes. The evolution of warfighting is not continuous but irregular. Analysts, however, differ in their views of what RMAs have occurred, in the role of different factors in affecting the emergence of an RMA, and in whether current RMAs are at the beginning, mid-point or end of their emergence. This report does not attempt to resolve these differences. It focuses on the issue of time or speed, i.e., on the question of how fast an RMA proceeds and why.

The analysis also accepts that the research of others ---- upon which the majority of the report is based --- represents a thorough examination of the history of RMAs and the factors that affected their progress. For example, the report assumes that those who have studied the evolution of carrier aviation, strategic bombing or mechanized warfare have identified the key factors and activities affecting their evolution. If there appear to be oversights or inconsistencies those are identified in this report.

[1] Footnotes are used extensively in this paper, both to provide references and to provide additional information for readers who may want further clarification of statements in the parent text. Some comments and examples in this paper are based on the experiences of the author, or on comments that have been relayed to him during interviews and discussions over the past several decades.

Definition and Description of RMAs

The term "Revolution in Military Affairs" (RMA) was coined in the 1980s in OSD as part of the evolution of a concept called the Military Technical Revolution (MTR). The Russians had been conducting research into the MTR, and they believed that major changes in warfare occurred in a non-continuous fashion. The Russians identified three such periods in the 20th Century, and they were particularly concerned in the 1970s-1980s with the changes in warfare being brought about by sensors, processing and precision weapons. Translations of their writings were read closely by analysts in DoD and led the Department to investigate the concept of MTRs. The term RMA was imposed on the research when the feeling among analysts was that too much attention was being given to the role of "technology" and to the word "military". Such changes in warfare seemed to involve broader issues of the social, economic and international climate of a nation and broader issues in the way militaries operated than just the technologies they employed.

An RMA is defined, therefore, as a period of time in which a fundamental change takes place in the manner in which war is fought. Technology innovations precipitate the change, which then results in the formulation of new concepts of operations, matching doctrinal adjustments, new types of military forces, and new skills being imparted to military personnel. The change in war fighting is not containable within a nation's borders; all nations are exposed to the undercurrents in technologies. A nation responds to those undercurrents with changes to its military capabilities that fit its strategic situation and its internal dynamics. Consequently, in reacting to an RMA nations differ in both their military changes and in their speed of change. At some point the different approaches may be tested in warfare, perhaps even (as occurred in World War II) between opposing nations that took different approaches to adapting to the same RMA.

Examples of past RMAs include:

- The Japanese and American developments in amphibious warfare, which were tested in the Pacific.

- The German's development of combined arms mobile mechanized and armored warfare --- often referred to as Blitzkrieg --- which proved to be very successful in the early days of World War II but which the Germans overstretched in attacking Russia.

- The American development of combined arms mobile mechanized and armored warfare, which they failed to pursue until the eve of World War II and then ---- with a huge industrial base ---- implemented in a few years.

- The contrasts between the U.S., Japan and Great Britain in the adoption of carrier warfare, in which the first two nations made great strides in the interwar period while the British --- for a number of strategic and internal reasons ---- lost the early leadership they had at the end of World War I.

- The American creation of strategic bombing, which opened up an entirely new dimension of warfare and changed concepts of depth in combat, and its comparison to the German's development of that capability.

The attention of OSD to the interwar period of 1920-1940 is understandable, if only because it was a period in which widespread technological change occurred in the U.S. and several nations began exploring new ways to fight wars. It also marked a relatively unique period for analysis, because the U.S. could be compared to other nations that also pursued the same RMAs. World War II presented a side-by-side or face-to-face evidence of the effectiveness of different approaches.

As to the post World War II RMAs, analysts have identified but not necessarily agreed on a comprehensive list. Those most often mentioned are listed below but almost none have been studied with the rigor of those in the interwar period: [2]

- Nuclear weapons, nuclear forces and nuclear power
- Precision weapons and precision strike
- C4ISR, information warfare and information operations
- Space as a new theater of operations and warfare
- Missile defense
- Undersea forces and combat
- Deep attack
- Network centric warfare
- Dominant battlespace superiority
- Long range power projection
- Area denial

[2] See, for example, Martinage pg 7-9. Watts' book on precision strike is a unique contribution, apparently the only attempt at a comprehensive assessment of one of these RMAs.

RMAs are considered evolutionary and not revolutionary events. The term "revolution" is meant more in the manner of describing an industrial revolution than a political revolution. Consequently, long time periods are assumed to be involved in their adoption. The new methods of warfare often exist in parallel with old methods. Moreover, an RMA may take place only in a part of a nation's military (e.g., strategic bombing could be developed independent of major changes in ground warfare). The sweeping change, therefore, could be somewhat isolated within the overall military structure of a country.

Factors affecting Speed of Adoption of RMAs

Analyses of RMAs indicate that at least 30 factors affect their speed. These in turn could be grouped into eight sets:

- Context (e.g., a nation's cultural traditions, national military experiences, and geopolitical, industrial, economic and demographic position.)
- Problems and opportunities (e.g., foreign threats, bureaucratic competition, crises, combat failures or successes, and new technologies or systems.)
- Understanding and solution development (e.g., new operational concepts, doctrine development, lessons learned, war games, field exercises, simulations, and analyses of the activities of other nations or opponents.)
- Equipping the force (e.g., development and production of technologies and systems; testing; development of industrial capacity; building of supporting infrastructures; and, use of private industry.)
- Organizational structures and practices (e.g., formation and use of test units, combat units, agencies, and headquarters; re-assignment of functions; changes in overall mix of forces; and, implementation of new processes, practices or standard operating procedures.)
- People development (e.g., use of career programs; training of military and civilian personnel; staff and unit training; and, practices in selecting, evaluating, promoting and assigning personnel.)
- Leadership (e.g., top level involvement, the role of enthusiasts and advocates, tactics in offsetting resistance, actions to reinforce behaviors, the positioning of people within an organization, and manipulating involved constituencies.)
- Resources (e.g., the allocation of funds, people, technologies, systems and organizational effort.)

Each of these categories is discussed below. When examining what either accelerated or retarded the speed of an RMA it is possible to identify some actions that were more influential than others. For example, reassigning all the skilled personnel can drain a military of expertise that takes years to replace (e.g., when the formation of the USAF removed virtually all the pilots from the Army in the late 1940s, and affected the speed with which helicopters were adopted.) However, a series of actions or events ---- not just one ---- determine the pace of an RMA. So, for example, in helicopter aviation the Army's success in the late 1950s was a combination of clever actions by Army leadership, changing career requirements, specially training senior officers, advances in helicopter controls, exploiting USAF resistance, and creating a special experimental unit. To accelerate an RMA, consequently, requires thinking about all these factors and how they interplay.[3]

[3] In addition RMAs take time, and during that time unpredictable events occur, or actions taken earlier will have unintended consequences. That means that during the course of an RMA actions can be taken to affect its speed (and content). For example, the Germans took a number of steps in 1918-1924 that in

Context

RMAs among different nations, or within different parts of a military in one nation, do not start on a level playing field. A number of conditions exist in the early part of an RMA which essentially set the stage upon which changes begin. These conditions ---- environmental factors over which little initial control can be exercised ---- can facilitate the changes, while others impede them.

The conditions (with examples) identified in various studies included the following:

- Recent military combat experience: In World War I the U.S. Army had limited combat experience with tanks (e.g., only one of seven cavalry regiments went to war and an Armor Force was created towards the war's end.) The Germans by contrast used tanks and fought against tanks on numerous occasions. They had more opportunities to be exposed to their potential.

- Military cultural traditions: The Germans, even before World War I, had developed within the officer corps strong predispositions to objective analyses of their own performance, aggressiveness in combat, and initiative on the battlefield. Their development of mobile armored warfare drew upon these traditions. Traditions in the U.S. Army --- while embracing aggressiveness and initiative in principle ---- in practice required officers to follow prescribed doctrine and emphasized following orders. These traditions had to be overcome to develop armored warfare, which did not occur until the late 1930s.

- Historical organizational structures, practices and assigned roles: Before World War I the USN had created a naval aviation branch to which all aviators were assigned. That branch provided a foundation on which carrier aviation emerged in the 1920-1930s. By contrast, the United Kingdom in 1918 merged its naval fliers into the RAF (creating the new military service that Billy Mitchell advocated for the U.S. in the 1920s). The resulting absence of that body of officers and enlisted men was a key factor in ending the UK's position as the world's leader in naval aviation.[4]

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combination accelerated the adoption of mobile armored warfare. The U.S. Army, having made the error of disbanding its armor force in 1920, had many opportunities in the 1920-1930s to increase the speed of change (e.g., in expanding instead of terminating the test unit in the late 1920s, in equipping mechanized cavalry units in the 1930s, or in conducting multi-divisional exercises before 1940.) The speed of an RMA is not predetermined by actions at its beginning.

[4] At the end of World War I the UK's 12 carriers exceeded the total of all other nations. By 1940 Japan and the U.S. held the lead. Many factors affected the UK demise --- e.g., absence of hulls to convert to large carriers, conviction that war would be in Europe, and substantial cutbacks in ship building. However, moving naval aviators to a unified air force had major consequences. For example, naval staffs lost all expertise on operational planning and in long range forecasting of war at sea involving aircraft. Moreover, air operations at sea are very different from on land and impact even the design of planes (e.g., the need for

- Industrial, economic and demographic positions: The USN and Army Air Corps benefited greatly by the major growth of the aviation industry in the U.S. in the interwar years. It provided a number of the essential technological advances that were subsequently used in military aviation --- retractable landing gears, stressed metal skins, variable pitch propellers, flaps, etc.

- Geopolitical positions: The UK's approach to carrier aviation was affected by its belief that these platforms would have to support a war in Europe and fleet engagements in that region. The US approach to carrier aviation was driven in part on the idea of long distance warfare in the Pacific. That shaped the Navy's evolving ideas for carrier size, armament and operation.

These types of external conditions in essence place demands on what militaries have to do in order to implement an RMA. For example, the U.S. Army needed active intervention by its leadership, an attention to personnel development, a careful study of warfare, and other actions to move into mobile armor warfare in the face of its limited combat experience, cultural traditions, and historical role. Yet the Army ---- through a number of Chiefs of Staffs and Secretaries of War --- was unable to do so, and was perhaps 10-15 years behind the Germans at the beginning of World War II. The Germans by contrast moved rapidly into combined arms mobile armored warfare because of their experience in World War I and geopolitical position, and because their military's cultural traditions did not so strongly resist such changes.

It cannot be denied that good fortune or "luck" also occurs. One of the seminal examples of this has been the Washington Naval Treaty of 1922, which set limits on capital ships. This presented the USN the opportunity to convert two cruisers to aircraft carriers. The Navy converted these to the Lexington and Saratoga, which were both over 30,000 tons and would eventually support 100 aircraft each. The UK stayed with their existing smaller carriers, which in turn limited their ability to support the numbers of aircraft and the weight of the sophisticated and more capable aircraft to emerge in the 1930s. "Luck" does not preclude moving forward in an RMA, but it does affect progress.[5]

Presence of problems or opportunities

At the early points of an RMA, and during the course of its adoption, problems or opportunities arise. These may be just part of the above context, or these may be actually

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stronger landing gears, salt air resistance and stronger spines for tail hooks). These were non-standard additions to land aircraft, and were resisted by an RAF committed to standardization.

[5] This does not say the UK could not have pursued heavy carriers; it just made that pursuit more difficult. "Luck" can be overstated. Organizations are "lucky" because they are present when an event occurs, have the capability to react to the event, recognize the opportunity it presents and then act to exploit it. The occurrence of the event may have been unpredictable and uncontrollable; the subsequent actions of a military are not.

created by the actions of others or the actions of participants or opponents within a military. The impact depends on their breadth (e.g., threat to the nation vs. threat to a military organization), the clarity of their existence (e.g., ambiguity or lack thereof as to their impact and immediacy), and the degree to which they are seen as threats or opportunities. They are a major motivating force in an RMA, and can obstruct or facilitate its speed. Problems seem to be more influential than opportunities, because they threaten the existing practices of a military and thus catch the attention of its people and organizations.

For example, the German military in 1919-1920 perceived an existential threat to the nation from four bordering states with greater military forces, while the absence of a clear existential threat was a general problem for the U.S. War and Navy Departments. Japan (orange), Great Britain (red) and Mexico (green) were used as standard enemies in the early 1930s. More influential in RMAs in the U.S. were the organizational threats. Billy Mitchell's drive to establish a separate air force only increased the Navy's commitment to carrier aviation. Mitchell created the opposite effect in the Army, where resistance to creating a separate armor branch was based in part on what had occurred in creating a separate air corps branch.

Opportunities can stimulate an RMA, even in the absence of a clear threat. Remarkable is the success of the Army Air Corps in the 1920-1930s in pursuing strategic bombing without an apparent national threat. This seems to have been based on the concentration of a number of enthusiastic officers able to exploit the emerging technology, the public's enthusiasm for flying, and the politics of aviation. Even without a clear threat the Navy also moved into carrier aviation. It saw aviation initially through an organizational lens of meeting an operational need for supporting existing practices of long range ship gunfire. Then it developed aviation as a new form of warfare at sea, fashioning an enemy force against which to test ideas and practices.[6]

The following are types of problems or opportunities that in the past have affected the overall pace of an RMA:

- Threats.
- Combat or crisis experiences.
- Major successes or failures.
- Advances in technologies and systems.

[6] Carrier aviation's conceptual expansion to an independent striking power is seen by RMA analysts as owing more to the efforts of senior military officers, early war gaming and at sea experimentation than to a national threat.

- RMA actions by friends and enemies.

- Competition for roles and missions.

In the absence of an existential national level problem, military organizations appear to view a possible RMA through the lens of their existing forecasts of potential enemies, the style of fighting to which they are accustomed, and their internal organizational structures and practices. That in turn can easily slow adoption rates of RMAs.

Developing understanding of the problems, opportunities and potential solutions

The pace of change is strongly influenced by how rapidly an RMA is understood and responses are formulated. RMAs are seldom clear at their outset as to their affects on warfighting, the precise concepts of fighting that should be adopted to respond to them, how a military should be organized and equipped, how much of the older military force should be retained, or how the transition should be accomplished. Indeed, early-on and throughout much of the transition period of an RMA there can be substantial uncertainty about such issues.[7] Solution paths can also be wrong.[8] And, the risks and uncertainties can actually play to the advantage of those who resist an RMA.

RMAs have demonstrated a number of means by which changes have been explored, studied and then solutions developed:

- Conducting lessons learned: The Germans formed 57 committees using over 200 senior officers to examine their performance --- and that of opponents ---- in World War I.[9]

- Studying the actions of opponents and allies: The American Army failed to follow closely the actions of the Germans in the 1920s and for part of the 1930s, while the Germans observed the developments of the militaries of nations on their borders.

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[7] Even in the German case, in 1920-1940 von Seeckt had much of the concept of warfare outlined in 1919, but it still required changes throughout the 1920s to establish some major aspects of combined arms mobile warfare.

[8] For example, in amphibious warfare both Japan and the U.S saw its importance in the interwar years for operations in the Pacific. The U.S., however, developed a more successful concept and underlying military structure. The Japanese essentially formulated a response which was shown to be inadequate to the demands of this form of war.

[9] Efforts at lessons learned do not necessarily mean the right answers will be picked. The Germans, for example, also had 27 committees studying tactical air. In 1920-1927 the chief of the air organization pioneered ground support. But because of the losses suffered in making air attacks in World War I the Germans decided against developing strategic bombing.

- Using wargames & exercises: The Navy conducted detailed board exercises at the Naval War College in 1920-1925 to develop concepts for carrier aviation. The Germans were conducting multi-divisional exercises in mobile combined arms warfare by 1926, whereas the U.S. Army did not do so until 1940.

- Testing and improving technologies and systems: The Army Air Corps bought numerous types of aircraft in the interwar period, stimulating the continual development of aviation technology. In carrier aviation the Navy in 1924-1926 used one carrier to improve aircraft operations at sea. It increased the number of supportable aircraft on the deck from 12 to 48, largely by operational innovations (e.g., deck parks).

- Developing new measures of effectiveness: In Navy exercises in 1920-1925 it determined that key measures of carrier effectiveness included numbers of sorties simultaneously aloft and first attacking enemy carriers not battleships. These measures were then used in experiments at sea to increase carrier operational practices.

- Developing new concepts of operations: The Germans in mobile armored warfare and the US Navy in carrier aviation developed the broad concepts for both forms of warfare within a decade after World War I. These were then implemented in doctrine, redesigning forces, training personnel and outfitting the new force.

Analysts see concepts of operations as a major step in adopting an RMA. Concepts can emerge quickly when intellectual traditions permit the generation of ideas that are different from accepted military thinking, and when top level leaders support and actively lead the conceptual thinking. Initial concepts often go through refinements as they are examined in exercises and tests. Concepts can even be largely completed far in advance of the technologies and systems to implement them.

Being able to apply a level of objective analysis ---- including penetrating and persistent critical thinking ---- appears to be an important component in influencing the pace and appropriateness of response to an RMA. The German military, for example, rapidly developed its overall concepts for mobile combined arms warfare, and its traditions of rigorous, objective analysis appear to have been a major factor. Those traditions in the 1920s and 1930s led to constant improvements in their military capabilities. Moreover, a lack of quality in thinking at the beginning and throughout implementing an RMA can have major deleterious impacts. For example, the Army Air Corps --- in its enthusiasm for a separate service and for flying --- ignored test results in the 1930s and created a bombing doctrine that led to unacceptable losses in 1943.[10] The payoffs from having

[10] In the early 1930s the Air Corps Tactical School (ACTS) concluded unescorted bombers could penetrate air defenses with acceptable losses. In 1931 a two week exercise involving 659 aircraft showed the bombers could not be stopped, but that was principally because there was no detection, early warning, and

personnel and organizations willing to conduct cold blooded self-assessments on a recurring basis seem to be very high.

Reshaping organizational structures & practices

The technologies and operational concepts of an RMA change the structure and practices of military units and their civilian support elements. The existing institutions and practices often face substantial overhaul (or disappearance and replacement). Evidence indicates this is very difficult to accomplish, because existing institutions view changes through the lens of their past experiences and their practices (i.e., their culture). That can lead them to overlook or misinterpret the RMA they are encountering, and to slow the rate at which they dispense with "proven" past practices for new ones. This can be particularly difficult in large organizations, and in those with long histories of patterns of behavior (often demonstrably successful).[11]

Examples of organizational change or failures to change are frequently cited in the literature. For example, the Germans created a motorized troop combat organization and career area in the 1920s because their leaders recognized that the existing cavalry branch was too resistant to new ideas of mobile warfare. The US Army by contrast disbanded its armor force in 1919, assigned tanks by law to the infantry in 1920 and then let the infantry and cavalry debate the role of tanks for 20 years. Its Armored Force was only re-established in 1940, and even then it was over the objections of the cavalry.

Most of the RMA analyses tend to focus on formal organizational changes, but informal or ad hoc structures often have an impact. For example, Eisenhower and Patton conducted tank warfare exercises at Fort Meade after World War I and in the evenings compared notes. The effort ended in 1919. Billy Mitchell surrounded himself with a staff of similar enthusiasts for air power. When he was demoted to colonel in 1926 that staff was broken up; one of its members, Hap Arnold, was banished from assignment in Washington from 1926 to 1936. In the Army's movement into helicopters in the 1950s an informal panel was setup to identify colonels likely to make general and then to send them to flight training in order to populate future general officer ranks with pilots. Over half the first class made general.[12]

C2 to vector interceptors. In 1933 another exercise was conducted and these gaps were closed. The bombers are intercepted in day and night, before and after striking the target, and loss rates were high. The results were ignored.

[11] Practices --- both informal and formal --- grow over the years to enable an organization to deal with repetitive situations and unanticipated ones. Some may be very explicit (e.g., the standard sequence of paragraphs of an operations order to insure all key topics are addressed). Some may grow out of tradition and beliefs (e.g., combat experience is necessary to be selected for high level promotion).

[12] The selection process picked 12 officers in each of two years to send to pilot training. In addition to focusing on excellent career histories the committee picked officers from different branches in order to obtain enthusiasm across the Army's major sub-elements.

Change involves both organizational structures (e.g., division TOEs, battlegroup ship mixes, and government agencies) and organizational practices (e.g., processes, SOPs, and rules of behavior). For example, the Germans created a new divisional structure in the early 1920s that added signal, reconnaissance and artillery units to the standard division. With few additions this was the divisional structure with which the Germans entered World War II fifteen years later. The U.S. Navy created a Bureau of Aeronautics in 1921 --- the first new bureau in over 50 years. That new bureau controlled the allocation of funds, the development of personnel, and investments in technology. It removed from other bureaus several activities that involved aviation, and in doing so it essentially created a power center that controlled naval aviation.

Organizational practices can be as influential as structural change. For example, the Army and Navy's acquisition of aircraft in the 1920s and 1930s involved contracting for new designs with one firm and then letting other firms compete for production. Design competitions were fixed price and often led to a company losing money on development. Occasionally they could not recover that in production, because another firm would win the manufacturing contract. The impact of these practices was that in the late 1930s companies refused to invest to expand production capacity in the run-up to the war because they did not trust assurances that contracts would follow.[13]

Organizational actions that affect the speed of an RMA include:

- Formal staffs at top levels of the military that lead the change.
- Informal organizations that promote the RMA.
- Establishment of units to test concepts (e.g., test or prototype units).
- Creation of new combat organizations and modification of existing ones (e.g., the appearance of the first separate units, first small units, first large units, and first headquarters elements).
- Creation of organizations for management (e.g., establishing agencies that control money, training, careers, and technologies).
- Establishment of organizations to educate and train personnel.
- Resolution of conflicts between organizations over missions, use of resources, use of personnel, and concepts.

[13] This study did not attempt to evaluate the weapon acquisition process of the DoD or its predecessor organizations, although comments in this paper will raise this topic as an influential factor in speed. What is notable is that the role of acquisition practices does not appear to have been incorporated in studies of various interwar RMAs (e.g., strategic bombing, mechanized warfare and carrier aviation).

- Disbanding of organizations that are sources of resistance and no longer important to new styles of warfare.

- Installation of processes or practices for acquiring systems and integrating them into the force.

Organizational resistance is not necessarily a bad practice, although criticisms of such resistance are common among analysts of RMAs. But, for example, the resistance of the Navy to the creation of a separate air force actually helped the progress of carrier aviation.[14] Bureaucracy can in fact be a constructive influence, because it resists giving up old methods that have often been shown to work, for new methods that have not. When that resistance is dysfunctional seems to be difficult to determine, except after the fact or as it is occurring (e.g., von Seeckt removing mechanized vehicles from control of the cavalry).[15]

Developing and equipping the force with new systems

RMAs require that the military force be equipped with the new technologies. That means that the pace of an RMA is influenced by the pace of the technologies, the pace of their implementation into systems, and the rate at which those systems are incorporated into the force. Moreover, it is not just the technologies and the systems that are important. It is also the technologies that underpin the manufacturing of those systems and the manufacturing capacity itself. All these elements place emphasis on a military developing an understanding of technologies, systems and manufacturing. One question is to what extent this can be delegated to civilian experts. The Germans, for example, emphasized technology education in academic training for its generals and for officers to be assigned to its General Staff; it also continued that education after the officers joined the staff. That is credited by analysts as important to the speed and insight the Germans developed into combined arms and mechanized warfare.

RMAs are stimulated by the appearance of new technologies, but it is difficult to establish precisely when this occurs. For example, the invention of the airplane could be used to mark the beginning of strategic bombing or carrier aviation, but the acceleration of interest in these two areas probably traces more to the early 1910s or the 1920s. The internal combustion engine --- an essential building block to mobile warfare ---- traces to the late 19th century, but the emergence of armored warfare is more usefully pegged to the introduction of the tank in World War I. There is some point early in an RMA when

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[14] In 1918-1919 there were eight separate pieces of legislation proposed in the Congress for an independent air service. So the pressure was substantial to replicate the British action of creating the RAF.
[15] One possible means for early detection of dysfunctional resistance is through early testing of new concepts in competition against old ones, which could provide indicators of the effectiveness of the new concepts while surfacing the willingness of organizations to absorb them.

new technology is manifested in an operational system ---- no matter how minimal ---- and stimulates a military to begin exploring an RMA change.

Moreover, multiple technologies are involved in the initiation of an RMA. Carrier aviation resulted from advances in aircraft components, in the overall design of aircraft, and in systems on carriers such as arresting gears and catapults. The tank was an assemblage of components (e.g., engines, transmissions, suspensions, guns and munitions); moreover, mobile warfare also was based on advances in trucks, aircraft and communications. The various technologies also change at different speeds and at different rates in different nations. [16] Engine technology, for example, does not progress at the same rate, or in close coordination, with communication technology.

Because multiple technologies are involved, an RMAs advance can be incremental as pieces of the technologies reach a usable status. Moreover, in RMAs involving complex linkages among systems (e.g., in precision strike or IiW) the dispersal of technologies also has two other attributes. First, RMAs can reach points of partial employment more quickly as pieces of the RMA can be fielded. For example, incremental improvements in ISR gave military forces greater ability to employ IiW throughout the 1980s and 1990s (i.e., unlike carrier aviation which had to await capable aircraft in the late 1930s to execute new operational concepts).[17] Second, the diversity provides a form of insurance against the failure of one branch of technology or system development. Much as networks provide alternative communication paths so message throughput is not stopped by link failures, in technologies the pursuit of multiple ways to meet requirements (e.g., for precise attack) means that one failed approach (e.g., a non working radar sensor) will not halt the overall effort (e.g., because EO and IR technologies are also pursued).

Technologies can both initiate an RMA and be the pacing elements in its final implementation. For example, in carrier aviation, the technologies of aircraft development were to go through major changes in the interwar period that made the emerging concepts of carrier warfare feasible. The concepts of large carrier operations were developed by 1929, far ahead of the aircraft capable of executing them. The Germans similarly had developed and trained their military in mobile armored warfare by 1929-1930, well ahead of better tank designs. RMAs may be triggered by technologies, then reach implementation in doctrine, organizations and personnel, but eventually have to await maturing or further advances of the technologies underpinning them.

Progress is also not smoothly continuous, but occurs seemingly in random steps and occasionally in radical improvements. Often, over time there emerges a "dominant design", a set of common characteristics in products and in manufacturing that are used

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[16] For example, in the development of strategic bombing the Army Air Corps was greatly assisted by the development of increasingly powerful engines. These supported development of aircraft such as the B-17, B-24 and B-29 for heavy long range bombardment. The Germans, however, did not succeed in developing similarly powerful engines, which limited their reach even over England.
[17] This should also provide opportunities to test new concepts earlier in an RMA.

by most producers and that are expected by most buyers. Those characteristics can change as technology changes, new uses appear, or users' needs change. Classic examples of this occurred in aviation, first in the appearance of various improvements in structures, skins, engines, wings and control surfaces, and then in the mid-1930s in a major step forward in integrating these in the design of the DC-3. [18] That aircraft combined technologies in propellers, flaps, engines, aerodynamics and other areas to produce the first twin engine aircraft that could economically move people.[19]

Technologies, moreover, transition from initial experimentation to the establishment of a scientific and engineering intellectual base of concepts, design practices, and recordable and teachable knowledge. In aviation, for example, from the early 1990s to the 1930s the designing of engines, controls, wings, structures, etc. remained largely experimental; designers learned by experience.[20] Developing and transferring a body of knowledge took decades. The Navy in 1919 collaborated with MIT to create the first masters program in aeronautical engineering, and in 1926 the Guggenheim Fund sponsored engineering programs being setup in nine universities. Not until the 1940s was there probably a body of literature, mathematics, engineering principles, research facilities, etc. that provided an engineering intellectual foundation for teaching people how to design and build aircraft.[21]

There appears to be a relationship between this gestation period for an intellectual engineering infrastructure and the speed of an RMA. Progress may be paced by the number of skilled people, breakthroughs, early applications and levels investment. As the intellectual structure begins to appear there is a larger base of trained engineers,

[18] The DC-3 was built by Douglas for TWA as a competitive reaction to the Boeing 247, which itself had been a radical step into twin engine commercial design. Boeing provided the 247 to National Airlines, its sister division, and that compelled other airlines to wait for years to buy copies. Douglas was commissioned to build a competing product (the DC-1, 2 and then DC-3). Its design was so dramatically better that the DC-3 was virtually the only aircraft bought by airlines in the U.S. from 1936 until World War II. For the first time, airlines could make a profit carrying only passengers (without mail). See Ray pg 63-76.

[19] A more contemporary example is the standard practice of hanging jet engines from wings in large aircraft, instead of burying them in the wings (as was done early in jet aviation in many designs). The approach reportedly was developed by the Germans in World War II and copied by Boeing in their B-47, B707 and B-52. It has dominated large aircraft design for a half century. Its major change was in the B-2, when the engines were buried to control their heat and other signatures. The concept of "dominant design" is related to issues of rates of change and disruptive change in technology. When an industry has embraced a dominant approach for long periods, the introduction of very different approaches can be difficult for existing firms to adopt and can change the structure of an industry. Consider, for example, the impact of front wheel drive in automobiles, the movement from film to digital photography, and the change in aviation from manpower intensive to capital intensive production techniques.

[20] Ray Chapter 1 & pages 217-219

[21] "During the two decades of flying, few universities offered courses specializing in the aeronautical sciences, but after 1926 the Guggenheim Fund greatly strengthened fundamental research … with endowments to nine universities strategically dispersed over the nation." Holley pg 22-23 As will be discussed later, this pattern was also seen in the evolution of computer hardware and software from its appearance in the 1940s to the body of standard languages, hardware design, and applications in the 1970s.

written design principles, and record of approaches that do not work. An RMA's speed may then depend less on advances in the technologies and more on the urgency of problems, recognition of opportunities, actions of organizations, and availability of resources. Moreover, when the engineering intellectual infrastructure is developed it is more difficult to control the passage of important knowledge to other militaries (both friendly and hostile).

The technology of manufacturing and the availability of manufacturing capability can be on the critical path to implementing an RMA. The experiences of the interwar period suggest that equipping the force --- particularly a large one --- may take as much or more time than developing effective systems. For example, the U.S. had no manufacturing plants for large scale production of tanks until after 1940. That paced the expansion of Army mechanized units, and mobilization enabled that to occur within a few years. However, production also adversely affected improving the tank as a weapon. Improvements were set aside in order to maintain high volume production and to avoid having to change the tooling in plants. German tanks were widely regarded as superior in firepower and armor for much of the war (although the Germans suffered from weaknesses in reliability from quickly introducing new designs). The RMA research on the interwar years appears to give little attention to these issues of production.[22]

RMAs may also be influenced by the degree to which private industry or government organizations are the used for technology development, system design or production. In combat aviation, for example, a large commercial industrial base developed in the U.S. in the interwar period and provided innovations as well as manufacturing capabilities. But in tanks, the U.S. government monopolized their design, prototyping and manufacturing in its arsenals. Government studies stated this occurred because there were few parallels to tanks in the private transportation sector. However, the Germans outsourced their tanks to competing firms in the interwar period, and that resulted in competing designs and innovations in systems. So there may be relationships between speeds of progress, the presence of monopolies or competition, and the degree of government and commercial involvement.

The following factors consequently may affect the speed of an RMA:

- Breakthroughs and major changes in technologies.
- Establishment of an engineering intellectual foundation.
- Development of dominant designs in systems and production.

[22] An issue in the current period is the capital intensity of such production. Modern manufacturing can involve major costs in facilities (e.g., clean rooms), precision tooling, and process controls. These can impose time delays measured in years to build or change capacities.

- Understanding of technologies, systems and manufacturing by military personnel.
- Early appearance of military systems.
- Deployment of systems in test and operational units.
- Use of technologies in combat.
- The technologies for manufacturing.
- Production capacity.
- The establishment of infrastructures to support the technologies.[23]

There is a complex relationship between equipping the force on one hand, and the speed with which a new concept of operation and matching force changes occur. Having a sufficient number of systems to conduct useful experimentation is important to speed. In carrier aviation the Navy had to have enough aircraft to conduct experiments in the mid-1920s and learn how to carry four times the number of aircraft on a carrier than originally projected. In the 1930s the AAC could buy 14 samples of any new aircraft before having to obtain Congressional permission for more. That enabled them to experiment at more than just a technical evaluation of a prototype.[24] The early availability of sufficient samples to begin experimenting with new concepts of operations seems to be an important issue in the pace of change.[25]

Developing skills for the RMA

Because RMAs incorporate wide scale use of new technologies and employ new force operational concepts (at tactical, operational and strategic levels), the personnel in the military have to acquire new skills. Consequently, the education and career development of the officer and enlisted ranks exert impacts on the speed of RMA adoption. Moreover,

[23]For example, the U.S. government's building of air traffic control and navigation systems enabled the development of commercial aviation, and thus stimulated developing better aircraft.
[24] In the absence of systems in the 1920s the Germans used wooden models in exercises to simulate mechanized vehicles.
[25] Considering the present day, this may also have implications for the manner in which the DoD approaches prototyping. One or two units may be sufficient for selecting a winning contractor, but not sufficient for maturing conceptual ideas about radical new ways of fighting. Moreover, long development times means that as many as 5-10 years can pass before enough copies of a system are available to test new operational concepts. The affect of prototyping on the speed of an RMA does not seem to have been examined. The use of simulation may not be an adequate substitute because users ---- when applying a system in exercises or combat --- discover new ways to employ them or problems that only occur when deployment takes place.

this skill training is not just at the individual level (e.g., pilot training); it also occurs at the levels of groups (e.g., combat units and staffs).[26]

In the interwar period there were striking contrasts in skill development among different militaries. For example, the Germans placed great emphasis on training the officers and senior enlisted men in new operational concepts. Equally important they emphasized aggressiveness, initiative and willingness to violate doctrine if the combat situation warranted it. They conducted exercises up to the level of the entire army and conducted rigorous after action evaluations. By contrast the U.S. Army discouraged creative action on the battlefield, dictated compliance with doctrine, and did not conduct comprehensive exercises and rigorous self-examination. The Germans moved into combined arms warfare about 15-20 years ahead of the U.S.

However, the challenge is to develop skills in the new RMA but not to separate the personnel so far from their military service as to impede their ability to influence the RMA's progress. For example, in the 1920s pilots in the U.S. Army avoided educational assignments to C&GS and the AWC. As a result, in 1929 only three pilots were eligible for general staff positions. This may have contributed to the fact that in 1933 of seven branches only two were under strength in officers. The Signal Corps was short 18, and the Army Air Corps was short 368. While the 1926 Air Corps Act authorized one major general and three brigadiers, also in 1933 none of 67 generals were Air Corps officers. By contrast Adm Moffett was credited with cleverly arranging career patterns among aviators to insure they were kept in the mainstream of the Navy and not relegated to a specialist role similar to engineering duty officers. .

Factors affecting the speed of an RMA include:

- Establishment of career programs.
- Promotion and assignment actions.
- Establishment of formal education activities.
- Routine practical skill training in units and staffs.
- Development of staff and support skills.
- Unit training, from the level of small units up to the entire military force.

[26] Analyses of the RMAs of the interwar period seem to give scant attention to the role of skill development among non-military personnel (e.g., senior civilian leaders, their staffs and civilians in arsenals). How the education of civilians affected RMAs' speed in 1920-1940 is unclear in the research. Moreover, following the war civilians played a much larger role in managing the military services. That includes not just government employees but also various non-government entities (e.g., companies and FFRDCs). Their role has also not been examined.

Skill development is considered by some analysts to be a factor that requires decades to propagate throughout a military force. This could be incorrect. The German military, for example, had trained at the individual and unit level (up to the entire Army) in mobile armored warfare by 1929, roughly a decade after it began wholesale rethinking of combat operations. The U.S. Army developed a skilled force in the same form of warfare in less than four years, starting with the formation of the Armor Force in 1940. Moreover, in most RMAs skill development does not necessarily involve all personnel and all units, and thus may be pursued more surgically.

Support of RMA by top level leaders and staffs

Leaders adopt the new RMA at some point in its evolution. On the one extreme is von Seeckt, who led the German army from 1919 to 1926 and led conceptual development, unit redesign, personnel development and army wide integration. On the other extreme are many Chiefs of Staff of the U.S. Army in 1919-1940, who actually banned armor units, disbanded various experiments, and separated themselves from any major role in developing concepts or forces in mobile armored warfare. Only in the mid-1930s --- faced with the changes in Europe --- did they begin to support wider attention to war other than as an infantry and cavalry oriented event.

Leaders become involved in the execution of the RMA, from the level of conceptual development and support, to shaping the organization and guiding personnel development, to engaging in the day-to-day actions. Moreover, there are certain tasks that only they can accomplish. This includes as creating staffs at the top of the military; selecting other leaders and positioning them; resolving internal differences among major sub-organizations; affecting the support of senior civilian government leaders; protecting those who undertake the daily tasks of implementation; setting an institutional climate for developing the RMA; and, positioning their own replacements for continuity of support. Leaders also do not just include the chief of a military service. They include senior civilians, political leaders, top level advisors, senior commanders and others who can exert major influence.[27]

A number of actions by leaders have been identified as affecting how fast an RMA progresses:

- Seeking knowledge about the emergence of an RMA.

[27] Civilian leaders in the interwar period appear to have had a lesser role in strategy and long range thinking than in the Cold War period. They were occasionally identified as being actors in the RMAs, as when the SecWar in 1927-1928 encouraged forming an experimental mechanized unit. In contrast to the period after 1945 "almost until the outbreak of World War II the civil government paid scant attention to war planning. Strategy was the domain of uniformed officers who neither got nor expected guidance from their civilian masters." (Miller pg 9-10)

- Coordinating with other leaders with similar views to their own.
- Exploiting problems and opportunities to move an RMA forward.
- Using high level boards and committees.
- Creating new leadership positions
- Ensuring continuity of leadership support.
- Involving themselves in analyzing and developing concepts.
- Providing enthusiasm, articulation and advocacy for an RMA.
- Recruiting external support.
- Assigning, re-assigning and replacing influential people.
- Resolving key issues.
- Supporting advocates.

Enthusiasm and determination are two attributes often seen as keys. The interwar period contains several examples of leaders forcing through major change by the intensity of their involvement (and, in Billy Mitchell's case over stepping so far as to derail his enterprise). Often these leaders bend the cultural and even formal procedures of their parent organization. For example, Adm Moffett used his political contacts to stay in office; in 1936 three officers bypassed the SecWar to reach FDR to obtain funds for more B-17s.[28]

Availability and allocations of resources

Resources include such elements as funding, personnel, facilities, technologies and systems. Availability and allocations, therefore, are not just about money. Moreover, all organizations have resource scarcities; the available resources are generally unable to support all potentially valuable investments. The RMAs in the interwar period have been seen by analysts to have been in an era of uniquely limited resources, and consequently, to be demonstrations ----- not in the level of resources ---- but in their allocation.

[28] The management literature today suggests that leadership involvement cannot be limited to occasional pronouncements of support. Major change requires substantial percentages of a leader's time (some indicate percentages like 20-40%).

In the interwar period the Germans moved forward in a period of major constraints on force size and weapons. The US Navy developed carrier aviation in the face of initially declining budgets (post 1918) and then low budgets (1925-1935). The Army Air Corps developed strategic bombing in the same situation. Some analysts have contended that such scarcity positively stimulates such innovations by presenting both problems and opportunities. On the other hand there does not appear to be a body of analysis of RMAs in less constrained environments (e.g., the Cold War), and research on innovations in general are less clear on the impact of scarcity.[29]

The factors in resources that can affect the speed of an RMA include:

- Funding key activities (e.g., experimentation, test units, exercises, innovative technologies, changes in facilities, new units, building staffs, education and training.)
- Investing in specific technologies or systems.
- Building underlying capabilities (e.g., knowledge and skills).
- Allocating key personnel, facilities and even organizations.
- Sustaining investments even in the face of failures.
- Protecting resources from diversion to other uses.
- Diverting resources from outmoded warfighting areas or uses.

It could be argued that resource levels are just a reflection of other factors. Thus the U.S. Army's lack of investment in tanks reflected the competition between the Infantry and Cavalry over how war is fought, and reflected the Ordnance Corps' unwillingness to invest without agreed requirements from the combat branches. The U.K.'s formation of the RAF largely determined how resources would be allocated, regardless of scarcity (indeed, it created a scarcity --- in naval aviators).[30]

[29] The innovation literature about both governments and companies suggests that success or failure in organizational change depends on many factors, of which resources are but one. Others include clarity of problem and opportunity, institutional aspects (e.g., organizational size, past experiences, internal practices, etc.), existing skills in its members and their transferability, sunk investments, technologies, system maturity, and actions of leaders and change agents. Scarcity, therefore, is a factor but more important may be how scarcity is managed.

[30] Moreover, when funding does increase, it can actually impede elements of an RMA. Thus, in the late 1930s the increase in military budgets for the Army Air Corps actually decreased investment in aircraft development because critical resources were directed toward manufacturing aircraft.

Three RMAs of Interwar Period

At tabs 1-3 are chronologies for three RMAs of the interwar period that demonstrate how the factors described in the previous section appeared in each case.

U.S. Army adoption of mechanized mobile warfare (Tab 1)

The U.S. Army made virtually no progress in mechanized warfare between 1918 and 1940:

- The Army's participation in World War I was actually limited (i.e., to the western front and with little involvement in mobile and tank warfare). Consequently, it was not significantly exposed to the experiences of armored war and mobility that might have stimulated movement to mechanized warfare. Its dominant combat arms --- infantry, cavalry and artillery --- were able to behave as they had for decades without undergoing experiences that would have brought into question their historical approaches to war.

- Following the war American society --- largely untouched by combat losses --- was essentially unconcerned about war. The Army's mission was basically border protection and did not include being prepared to fight wars overseas. Isolationism and commercial prosperity moved to the forefront. Then in the Great Depression economic recovery became the key focus. In essence there was no foundation of public support or concern to influence the Army's concepts of war.

- The Army underwent a substantial reduction in funding and resources in the 1920-1930s. The Army leaders did not step forward with the enthusiasm of a Billy Mitchell to shift resources. Indeed, the draining of funds for the Army Air Corps actually caused the Army leadership to reject developing an armor force for fear of creating another combat branch like the Air Corps. Instead the Army allocated scarce funding among its traditional missions and organizations. The Ordnance Corps, for example, allotted only enough money to build one R&D tank a year.

- With border security as its historical and primary role and little exposure to changes in major warfare, the Army in the 1920-1930s was largely ruled by its major sub-organizations (i.e., branches), which in turn had few experiences to force them to alter past practices. The infantry viewed tanks as mobile pillboxes moving no faster than a foot soldier. The cavalry continued to focus on horses and patrolling the Mexican border. The competition between the two branches dissipated resources for armor development. This was exacerbated by the Ordnance Corps, which had historically determined what weapons to build, but in 1918 began a seemingly logical policy of not developing weapons until the requirement was certified by the combat arms. Without agreements among the combat arms on types of tanks, few were even developed.

- Overarching this organizational behavior were the cultural aspects of the Army. Periodic re-assignment of top leaders lessened the chance that continuous pressures would be applied for change. The Army's educational practices did not emphasize innovative thinking, even at the level of tactics. Officers who tested the limits of existing practices were even threatened or punished. While there was some debate over doctrine and tanks starting in the late 1920s it remained isolated.

One could speculate on how the Army could have moved more quickly, even within the context of its limited interwar mission and its limited resources.

- It could have conducted more comprehensive analyses of World War I and its performance. It could then have followed that research in the interwar years with further thinking about the future of warfare, even if it did not pursue that thinking to the level of conducting exercises or forming experimental units.

- In contrast to the actions of Gen Pershing, in 1920 the Army could have retained as a major organization the Armor Force. That would have created the exact competition for resources that led Pershing to terminate it, but it would also have provided a focal point for concepts, force developments, and pursuits of technology and systems.

- Top level Army leadership could have provided continuity of support for developing mobile armor warfare, even as they rotated through assignments.[31]

- The Ordnance Corps could have returned to its historical roots of dictating the weapons of the Army, and might thus have made more progress in tank design and armament.[32]

- Collecting and using knowledge of what European states (including Russia) were considering in ground warfare would have shown contrasts between the Army and other militaries.

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[31] COS Summerall, for example, setup the experimental unit in 1927, only to have his successor (MacArthur) disband the unit, assign its pieces to the cavalry, and reassign tank doctrine, training and development to the infantry. Ironically MacArthur supported the mechanization of warfare; he broke up the unit because of the limits on Army funds and the friction between the infantry and cavalry. Chiefs of Cavalry supported mechanization from 1930 to 1938, only to have it halted by a new branch chief.

[32] For example, as early as 1918 that branch foresaw tanks needing 75mm guns, and in the 1930s pressed for more effective weapons than 37mm. However, compliance with its own policy of seeking user validated requirements led to halting such efforts.

- The Army could have changed its educational practices, career management and performance expectations for its officers and enlisted men to create a more thoughtful, innovative and aggressive set of personnel.[33]

While the RMA literature is critical of the Army's lack of advance in mobile armor warfare in 1918-1940, there is in fact an interesting and more positive story. Once World War II broke out, the Army moved from basically a partially equipped regiment of armor (a cavalry regiment) in 1940 to fielding 16 armor divisions by 1944. That achievement in about four years indicates that RMAs can progress at very high rates of speed under certain conditions.

German adoption of mechanized mobile warfare (Tab 2)

The German development of this form of warfare provided examples of almost every factor to rapidly adopt an RMA.

- In the German's loss of World War I its military recognized their failures. They studied their performance and the performance of others, forecasted the course of future warfare, and in the early 1920s set about at all levels to change the German military. In addition they maintained practices of rigorous review of their performance in order to improve on their progress. Their leadership --- especially von Seeckt --- provided both conceptual and practical leadership, and maintained that continuously for over a decade.

- The allied victory inadvertently assisted their efforts. The allies imposed major reductions in the German military, which gave von Seeckt the opportunity to quickly drop people who might have resisted adopting new forms of warfare. Getting rid of weapons removed much of its older equipment that might have impeded arming a new kind of force. Personnel restrictions created incentives for the German military to focus on high quality manpower at all ranks. Four border nations presented a constant existential threat that drove the military to think about how to fight on multiple fronts with little warning against stronger opponents.

- The German Army already had a strong military culture in 1918, and its leadership sustained the applicable aspects of that. They reshaped the military from a conscript to a professional force. They changed the acquisition, training and development of personnel. They restructured their military organization around the demands of new forms of war and the professional military they were

[33] This would have had some affect on the actions and thinking of senior officers, many of whom seem to have given some thought to mechanization and its impact, but lacked either the background or the underpinnings of innovative junior officers to push for change.

developing. They then exercised the structure all the way up to the full German Army on a periodic basis.

The chronology demonstrates how fast an RMA can progress if virtually all of the eight categories of actions are employed. While the Germans may not have had much of the equipment for major warfare until the late 1930s, the impression is that their basic institutional structure and military personnel were so competent by the late 1920s that they could have defeated any western military on the ground.

Perhaps two factors are the most interesting in examining Germany's speed.

- First, they developed in their enlisted and officers ranks a blend of tactical aggressiveness, initiative, openness to change and strategic focus. That was accomplished by intense attention to recruiting, educating, evaluating and assigning personnel. The impact was probably to neutralize much of the resistance that could have developed, although they still had to re-assign motorized units from the cavalry because the cavalry was seen as too resistant to change.

- Second, in creating the change the German Army demonstrated how to bring together three very challenging elements ---- the abstract concepts about warfare (e.g., the notion of friction), a broad strategy or concept for how to use military force, and a pragmatic set of actions to implement the concept. From the conceptual to the practical they seem to have integrated these elements through techniques that almost parallel current concepts of modern management. They created a highly skilled top level staff that could execute the changes; they moved control of both technology and doctrine into the staff to insure top level control; they re-organized units to support their ideas; they isolated pockets of potential resistance; they used practical means like exercises to manage (not eliminate) the basic uncertainty and risk of combat; and, their top level leadership demonstrated the behaviors they were demanding of their subordinates.

As some authors remarked, even in the losing days of 1945 German soldiers and units were generally more effective on the battlefield than the opposing allied units. Their mistakes in World War II were in attempting too much for the forces they had.

U.S. Navy adoption of carrier aviation (Tab 3)

The Navy's adoption of the multi-carrier task force in 1943 is seen by some analysts as the end point in this RMA. Its speed of adoption can be credited to several major factors:

- The airplane was initially seen as supporting the existing major approach to naval warfare. The Navy became interested in using it to scout and direct fires for the battle fleet. It was --- in that role --- an adjunct, not a competitor to the manner in which the Navy operated. Before World War I a career program had been established, planes were being procured and aviations use was being explored.[34]

- In the years immediately after World War I the high levels of the Navy remained interested and involved in aviation. The General Board studied it and made recommendations to the SecNav, and the first new bureau in 50 years was established.

- People with a grander vision for aviation --- and for how it would affect the structure of the Navy --- came from within the Navy, and even from its mainstream combat element. They took insightful steps in developing naval officers with flight experience, in ensuring those officers had careers that made them part of the mainstream Navy, and in using political influence to shape support for naval aviation. They also sponsored the analysis of how aviation could change the war at sea, used the educational structure to develop naval aviation, and demonstrated the usefulness of aviation in exercises.

- In a period of scarce resources the Navy increased the portions of its spending in aviation. It was fortunate enough to have two ships that could be converted to carriers under the 1922 agreement, and in fact made the choice to do so. It had a growing and enthusiastic private sector aviation industry that provided new ideas despite a debilitating set of government acquisition practices and a government operated set of arsenals.

- Pearl Harbor forced reliance on the few numbers of carriers left in the Pacific, and the conceptual developments of the 1920s-1930s were brought to bear in a period of crisis.

It is hard to identify steps which could have accelerated this RMA. Aviation technology in particular has been identified as not being adequate until the late 1930s. Had the Navy managed its relationships with the aviation industry more adeptly it might have accelerated aircraft developments in the 1930s and mobilization in the late 1930s. The fact that it forced companies to lose money on R&D aircraft, for example, led firms to lessen their exploration of new designs; proven designs were less risky. In the build-up to World War II companies refused to invest for production capacity because they had been left without contracts when responding to non-contractual requests in the past.

[34] This suggests that one framework for analyzing RMAs could be to segregate them into three sets ---- those that initially improve existing means of fighting (e.g., carrier aviation, precision strike, nuclear submarines), those that replace existing means (e.g., tanks over horses), and those that open up new arenas of war (e.g., strategic bombing, nuclear weapons, space). Resistance to implementation and thus to speed may differ in these categories.

Observations on the Interwar Period

These three cases demonstrate that speed of change does not come from just one of the eight sets of variables discussed earlier, but comes from the interplay among many of them. From examining these three RMAs (and others described as part of the interwar period) there appear to be several topics that could be examined in more detail.

RMAs can takes 30-40 years.

The interwar period is bracketed by two world wars, which provided kick-off points and then benchmarks of progress. While useful analytically these may have distorted expectations for timelines for RMAs in the 20th Century, leading analysts to believe RMAs require about two decades. In reality these RMAs appear to involve 30-40 years, in the absence of major external pressures.[35]

For example, the U.S. Navy's adoption of carrier warfare probably dates from around 1910. Had Pearl Harbor not occurred, however, the final steps towards carrier task forces could have taken another decade or more. Carrier aviation, consequently, could have taken 35-40 years. In considering the Army's adoption of mobile armor warfare, one could place the start date in 1916 when the tank first appeared. World War II ended the Army's resistance and accelerated the equipping of major combat units. Absent the war, the Army could have struggled with this for at least another decade, and this RMA could have required 30-40 years.

On the other hand RMAs may also be achievable in very short periods of time.

When the many factors involved in an RMA are individually examined, their timelines for implementation can be short. Concepts emerged in as few as five years, unit development and training in less than ten, training personnel in new skills also in less than ten, and new career fields in less than a decade. For example, the Germans appear to have accomplished many steps by 1926 (about 8 years). Exercises up to the entire German Army occurred by about the 10th year. The American Army ---- having done virtually nothing in mechanized armor warfare from 1920 to 1940 ---- in the space of less than four years (1940-1943) created and equipped an armor force of 16 divisions.[36]

There appears to be little research in measuring what affects the speed of an RMA.

Analysts appear to measure the interwar RMAs tend against performance in World War II. The war demonstrated opposing nations' responses to the same RMAs (e.g., the U.S. vs. Japan in carrier aviation and the Germans vs. the Americans in mobile armor

[35] Analysts may also have been subtly influenced by describing the term "revolution" as being similar to "industrial revolution" vice "political revolution".
[36] A special case may also be the use of nuclear weapons, which appear to move from the level of science to actual deployment in less than a decade.

warfare.) Since that war, only Watts' study of precision strike probes the issues of measurement (in that case using metrics such as percentage of bombs using guidance). Measurement can be overdone. Wars since 1945 have involved different styles of conflict (e.g., Korea, Vietnam) or overwhelming differences in military force capabilities (e.g., Desert Storm). Measuring combat outcomes beforehand has always been difficult. Very complex strategic change does not yield to simple metrics. Nonetheless, there are interesting questions: what measures when an RMA has been achieved (e.g., as one analysts concluded occurred in 1943 in carrier aviation)? What measures the affect of different factors on the speed of an RMA (e.g., what is the impact of resource levels as opposed to organizational change, or early leadership vs. early experience)?

Relying too heavily on peer-to peer measures is too narrow. If speed were to be a focus, it might be measured (1) against some absolute criteria, (2) against the rate at which others adopt the same RMA, (3) against the improvement of U.S. force effectiveness, (4) against how an opponent's behavior can be shaped, or (5) against the warfighting styles of opponents (e.g., precision strike vs. terrorism).[37]

<u>Technology both stimulates and can constrain the speed of adopting an RMA, and a key constraint can be the time required to equip the force.</u>

All studies agree that technology is a key factor in initiating an RMA. However, the analyses seem less thorough in examining how the evolution of technology during an RMA affected its pace. For example, analysts point out that it was not until the late 1930s that aircraft design and engine power provided aircraft capable of conducting the new form of naval warfare. On the other hand, these analyses do not examine why that time delay occurred, how the Navy affected it, and what was occurring in the underlying industrial base.

Moreover, the technologies of a system can be very different from the technologies needed to produce it. A famous example of the challenges of production was Ford's commitment to producing B-24 bombers. The transition from making cars with steel to making aircraft with aluminum presented challenges in manufacturing technology and

[37] It may also be useful to examine RMAs of the current period in different groups. These could be RMAs that could have existential implications for the U.S. (e.g., information warfare that collapses the economy), RMAs in which there are low probabilities of existential effects (e.g., precision strike in insurgent warfare), RMAs in which peer to peer confrontations might occur (e.g., U.S. vs. China in military use of space), and RMAs by which the U.S. improves military effectiveness.

processes.[38] Past studies appear to have stopped short of examining the role of technology of production, and its impact on the RMA.[39]

<u>The participation of private industry has received little attention in analyses but appears to affect the speed of RMAs.</u>

In America, for example, both strategic bombing and carrier aviation benefited from the technology advances in commercial aviation. The American public enthusiastically embraced aviation, a number of companies were created, the industry was a favorite of the stock market, and the government established the infrastructure to support its development as a means of transportation. Even when the government forced companies into losing money on projects, the firms used capital generated by stock offerings to self-fund designing military aircraft.[40]

There appears to be little research into the relationship between the activities of private industry and the pace of RMAs in the interwar period. Yet, this may be an important issue in current RMAs where technology may be more central to progress, private industry sets the pace of that progress, and the private sector in general develops the underlying engineering intellectual infrastructure. Understanding the role of industry may be particularly important in the current day, because firms have been distancing themselves from defense work.

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[38] The story of this transition includes the fact that steel which was used for cars ---- once stamped into form --- did not bounce back. Aluminum ---- used for aircraft ---- did. Ford engineers had to learn how to deal with this and many other differences in building the production line. Drawings of the B-24 had to be redone several times (the original 30,000 drawings were redone); of 21,000 tools made only about 11,000 were used. Ford was very successful in producing the B-24 but its manufacturing operation was very different from that of Consolidated. (Holley pg 518-529)

[39] The importance of the production side --- as opposed to the product side ---- of RMA systems is evident today in the micro-electronics that underpin precision strike and information in warfare. In developing new versions of solid state devices the ability to manufacture the devices is developed in parallel with the innovation in the devices. In contrast to aircraft, micro-electronics can also move very fast. A high performance military aircraft can take four or more years to be accepted as a design, and another five or more years to begin series production. A solid state device can proceed from design to production to obsolescence in 2-4 years (essentially its entire product life cycle). That suggests that RMAs built around micro-electronics can progress rapidly ---- not only to equipping the force, but actually through generational and operational improvements. The constraint on speed may have more to do with military acquisition and doctrinal practices than with the pace of manufacturing. That in itself would be a major change from the interwar period.

[40] The interplay between commercial and military in aviation was not smooth. During 1918-1935 there were over a dozen Congressional and Executive branch studies or investigations of military aircraft production, and adverse public opinion about weapons production affected the willingness of companies to design military aircraft. By the mid-1930s there were over 20 aircraft manufacturers, but only four produced over 80% of the aircraft of the Army and Navy. When the Air Corps asked manufacturers to expand capacity as part of mobilization in 1939-1940, the companies refused until formal contracts were signed. Mobilization was delayed by as much as a year.

<u>There are areas of research in the interwar RMAs that do not seem to have been investigated.</u>

In addition to the issues of technology, manufacturing and private industry mentioned above the historical studies do not appear to have examined other factors which seem to have an impact on the pace of an RMA:

- The acquisition practices of the military.
- Development of the underlying engineering intellectual structure.
- The use of prototypes.
- The influence of civilian personnel (in addition to just those in political positions).
- Training and development of civilian personnel.
- The role of informal organizations.
- The time commitments of key leaders.

RMAs in the Cold War and Post Cold War Period

Two chronologies were assembled for RMAs of the current period --- precision strike (PS) and information in warfare (IiW). Each provides a different perspective on RMAs, and raises questions in thinking about the content and the speed of such revolutions. Unlike the interwar period there appears to be few comprehensive analyses of these as RMAs.

Information in Warfare (IiW) (TAB 4)

Information is a characteristic of virtually all aspects of combat operations and strategy, from the development of peacetime defense strategy, to the formulation of military-political strategy in an actual conflict, to the types of fights that occur. In that sense, as an RMA it may be more useful to think of IiW as an element that changes multiple concepts of operations, in much the same way that internal combustion technologies changed many dimensions of warfare. It is an RMA in the sense that it underpins many RMAs.[41]

The chronology at Tab 4 indicates that this RMA ---- or multiple RMAs underpinned by the revolution in information ---- has been through several major periods.

- For the American military and society in general the period from 1950 to 1980 was one in which major changes occurred in the underlying technologies of information (e.g., in computer hardware and software, micro-electronics, the development of applications, satellite technology, and communications). That period was also marked by substantial DoD leadership in the technologies and applications.[42] After 1980 the technologies spread at an accelerated rate through American society and the world overall.[43]

- The military's implementations from 1950 through the 1980s were largely focused on solving problems or improving performance in existing military functions such as intelligence, communications, logistics, administration and C2. In the late 1970s technologies and demands of warfare began altering the strong separation between functions, between the doctrinal roles of individual military

[41] As some authors have noted, maybe the industrial revolution has given way to the information revolution. That framework may be important to thinking about IiW.
[42] For example, DoD built large computer based information and C2 systems, developed satellite communications and sensor systems, pursued innovations in communications networking, and took an active role in setting engineering standards.
[43] The development in technologies and applications in the non-defense sector had been increasing since the 1960s. In the 1980s this commercial sector is widely believed to have begun to move faster than the military in developing technologies, although the military's advances in ISR and communications were still improving its operations dramatically (e.g., giving commanders access to near real time satellite collection).

forces, and between national and tactical activities. For example, national level satellite imagery began providing real time collection and broad dissemination, overcoming time delays that had limited its value to combat commanders. Also, overcoming the threat of second echelon Soviet forces led to the Army and Air Force having to integrate their C4ISR and weapon employment practices.

- Desert Storm then demonstrated the strengths and weaknesses of using information in a more integrated set of military forces, at a more closely tied national and tactical level, and in ways to disrupt an enemy. While not entirely successful by this time (1991) expectations were developing that there should be an integrated worldwide linkage, flow and use of information in C4ISR, logistic support, etc.[44] Separate military services or agencies were seen as a reality, but the adverse impact of their separateness on producing and sharing information was something to rectify. Units could own information assets but should not be able to limit access to their output or even in some cases to their employment.

- In the 1990s thinking about information began to broaden. Cybersecurity, non-state actors, etc. raised information to a level that embraced both traditional military operations and new aspects of national security.[45] Policies were formulated from the level of the White House down to the military itself. DoD documents expanded IiW from intelligence and C2 into broader concepts, including information as a stand alone form of war.[46] People began to talk about winning wars based on superior knowledge and its exploitation, and by coupling systems together (e.g., DBA and SOS). By the early 2000 major organizations had been formed in the military services and joint commands with lead roles in information.[47]

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[44] For example, in 1980 commanders of units probably never considered shortfalls in imagery delivery from national collectors because they had only been minimally exposed to it weeks after collection. By 1991 commanders were complaining that satellite results were delivered in hours when they were needed in minutes, and that they had to compete with national needs and the needs of other field commanders in tapping these assets.

[45] As raised by some authors this also has created unresolved challenges in civil military relationships. Because information is easy to disseminate and moves rapidly, it can cross organizational boundaries quickly. Consequently, the institutional separations such as between law enforcement and military organizations can be bridged quickly and at low levels. This has raised fundamental questions such as how does the U.S. use intelligence in law enforcement? To what extent can the information systems of the military be used in attacking criminals? To what extent can it reveal its classified knowledge of cyberattacks, security and countermeasures to fine tune or reinforce activities in the civil sector?

[46] The Army in 1993, for example, was already thinking about broader visions (some of which in fact came to pass by 2009).

[47] A rough indicator of this may be the publicly identified reports of the DSB. In 1980-1989 there were 7-10 studies that addressed IiW topics, mostly on specific technologies. In 1990-1999 there were 12-15 such studies, some broadening to focus on systems and networks. In 2000-2010 there were 20-30 studies touching on IiW topics.

By the mid-1990s most of the factors for implementing an RMA seem to have been in place. Threats at a national level were appearing and being recognized. Combat experience had been demonstrating the value of IiW and weaknesses in its implementation. Top level leaders --- and major DoD organizations --- were articulating ideas and experimenting with IiW, including beginning to think about broader impacts than just improving current military functions. Military units and agencies were investing in systems for IiW; units were being created around IiW; and, people were skilled in working with the technology. The combat actions of 2001-2010 reinforced these trends.

The table below tabulates the points which the chronology indicates have exerted substantial influence over the speed of IiW as an RMA since about 1980.[48]

Factors	Supporting Speed	Retarding Speed
Context	▪ Technology and consumer advances in 1950-1980 laid the ground work in IT for an expanded role of information in warfare. This included advances in communications and computers; worldwide commercialization; and, development of engineering knowledge. ▪ Military personnel entering after 1980 have been increasingly familiar with the use and value of IT.	▪ Demand, and thus opportunities for growth in the commercial sectors, have diverted skilled personnel, company R&D investments, product development and company interest in defense products away from military applications.
Problem or Opportunity	▪ Combat experience in 1991 & in 2003-2009 demonstrated the value of information. Desert Storm was a seminal event in surfacing both advantages and needed improvements. ▪ Cyber attacks in 1990-2010 have raised the threat to a national level concern and generated policy guidelines and investment actions. ▪ Countering IEDs, individual terrorists and insurgent groups have led to concepts and investments for 24/7 coverage and targeting.	▪ While Iraq and Afghanistan have led to improvements in the acquisition and use of information, they have also diverted attention from looking at the potential challenges of long term competition against a peer competitor, and IT's strategic role in it. ▪ IiW is inherently a joint service and agency RMA. The development of networks among DoD systems in order to improve IiW are slowed by the large number of legacy systems, divisions among military services and agencies, the absence of engineering standards, and the lack of skilled personnel in system engineering.
Understanding & Potential Solutions	▪ Conceptual thinking about IiW as an RMA began in the 1980s. ▪ IiW has been a major element in	▪ While IiW seems firmly incorporated into strategy, it appears to be focused on improvements in existing combat

[48] A table is used because actions and events do not all clearly support or delay an RMA. The list also demonstrates that speed is affected by many factors.

	DoD strategy and planning documents since the 1990s. ▪ The military services have been thinking about the impact of IiW and major future changes since at least the mid-1990s. ▪ New ideas for military concepts have been surfaced, such as DBA and NCW. ▪ Exercises, wargames and analyses have demonstrated the positive impact of information on combat operations.	functions. Attention seems to be lacking in thinking about it as a much broader concept in warfare; statements are made but action seems limited. ▪ Emphasis on RMA as a concept --- and on peer to peer struggle --- appears to have declined since the 1990s.
Organization and Change	▪ Policies, planning and doctrinal statements have endorsed IiW. ▪ Agencies, militaries and joint forces have established sections, commands & agencies to focus on IiW, including focusing on it as a broad issue. ▪ Combat level units have been established with information warfare roles. ▪ OSD has established acquisition processes to bypass its conventional and more lengthy process.	▪ Plans and policies have not been fully supported by detailed actions. ▪ Government acquisition practices (e.g., Buy America, protection of proprietary information, intrusive accounting and oversight practices, and long acquisition cycles) have led to decreases in the numbers of firms accessible to DoD. ▪ Major projects in C4ISR remain under the DoD's lengthy acquisition processes and have not been delivered when required. ▪ The military and JCS remain divided in their organizational approaches and their priorities for actions.
Equipping Forces	▪ Technology has provided systems to support IiW (i.e., UAVs, satellite collection, internet like connectivity, PCs, GPS, etc). ▪ Communications systems have been providing high volume data and voice from tactical to national level. ▪ Military units have been equipped with systems to enable them to use IiW (e.g., EW systems, C2CM systems, UAVs, etc.)	▪ Military forces have a mix of legacy and new systems, and progress in integrating them has been slow. ▪ Major programs to outfit the military have been delayed because companies have not performed and the government has not managed them to meet schedule and costs. ▪ DoD acquisition practices have assumed products will last for decades and thus have not been attuned to the rates of change in technology underpinning IiW. ▪ The DoD management of requirements and programs has not matched the speed of changes in the technologies. ▪ Standardization and interoperability of systems remain incomplete.
Developing Personnel	▪ The military has been training its personnel in various aspects of IiW.	▪ The military appears to place IT – not as a separate branch – but as a skill to be added to existing branches (e.g., signal corps) or functions (e.g., USAF

		intelligence, and Navy engineer sub-specialty).
Top Level Support	▪ Civilian and military leaders from President on down have been signing policies or speaking about the importance of information to national security.	▪ Top leaders have not provided continuity of emphasis on IiW as an RMA since about 1995.
Allocating Resources	▪ DoD spending in many IT areas has continue to grow (e.g., ISR systems, C2, processing, UAVs, satellite collection and communications).	▪ Combat operations may be drawing funding from broader IT actions (e.g., more experimental exercises).

The pace of this RMA has been adversely influenced by the following factors:

- Most RMAs have been associated with the leadership of top level people who individually and collectively provided a continuity of support. In IiW, no one seems to fit this description. Owens and Cebrowski are often cited, but neither man's vigorous role was adopted by other leaders when they left the stage. They did not apparently provide for continuity of advocacy; neither also seemed to have been deeply involved in altering the educational and career management programs of the military services (which have been shown to be important in previous RMAs).

- This is a very difficult of RMAs to implement. The technologies are complex and changing rapidly; it involves very complex insertions into existing military systems and activities; and, it crosses multiple organizational boundaries. [49] However, the organizational structures and processes for integrating such diverse efforts do not appear to be strong enough to accomplish this integration; legacy systems slow advances; and, the discipline of system engineering at systems of systems levels is still emerging. Perhaps most challenging is that "information" is an abstract notion, difficult to comprehend in comparison to more physical assets like weapons and units.

- It is not clear that enough attention has been given to the value of information and what advances are important.[50] The link between information and decision, and

[49] For example, installing systems in a Navy ship or an Air Force aircraft involves problems of space, power, cabling, weight, platform effects, etc. Compounding that is the need to remove older equipment, coordinate that with similar changes in other platforms, and then validate that the new system will perform in its ties to the systems in the ship or aircraft. Then the question is "does this system provide more combat power than additional bombs or missiles?"

[50] For an analysis of the effectiveness of ORSA techniques in ISR, see the DSB 2009 study. In addition to examining ORSA in the intelligence community and services, it compared DoD's use to that by FedEx. The report concluded that "OR is in decline and not universally valued in decision making, especially at the strategic level, and with respect to investment decisions and systems acquisition." (pg 27)

between information and action, seem not to have been well analyzed. For example, complaints about the lack of communications capacity are the same as in the 1960s; communications always grows to exceed the supply; and, yet buying more communications remains a high priority.[51] One of the next major steps in this RMA may be advances in analyzing the value of information and where the greatest marginal returns would occur in follow-on investments.

- In general, technologies and systems appear to be more significant factors in IiW than in the RMAs of the interwar period. It is not clear that the dynamics of the evolution of these technologies are being adequately weighed. How does their rate of progress affect the speed with which the military force can evolve? What is the relationship between that speed and the militaries' approach to acquiring new technologies and retaining old ones? How does the industrial base affect the speed of the RMA? How do the competencies of other nations affect the comparative advantage of the U.S.?

IiW impacts warfighting in so many areas that it appears the best way to assess its speed as an RMA may not be to examine it at this level. It ma be better to study IiW as it has evolved in different parts of warfare. For example, it could be studied for its impact in different functional areas (e.g., C2, logistics, ISR, etc.), for its impact on current and future warfighting areas (e.g., in ballistic missile defense, counter-insurgency, space operations), or for its impact as an entirely new arena of combat operations (e.g., cyberwar).

Precision Strike (PS) (Tab 5)

The chronology at tab 5 suggests there have been three major periods in the development of capabilities to strike targets with great precision.

- <u>Specialization period</u>: The initial phase of precision strike ---- beginning in the 1960s --- involved weapons that entailed substantial cost, required special equipment on platforms or necessitated changes in existing methods for attacking targets. This was largely the period of the Laser Guided Bomb (LGB), which arrived in the 1960s, dominated into the 1990s and has remained an important element of precision strike. In the 1970s conventionally armed cruise missiles, both longer range (e.g., ALCM and Tomahawk) and shorter range (e.g., Harpoon) were introduced.

[51] See, for example, recently reported difficulties with the large volume of video being broadcast from UAVs, while the DoD has instructed the USAF in the QDR to increase the number of UAV orbits. Consider also that TSAT was terminated and JTRS has been delayed. People have voiced concern about not having enough communications capacity because of these events, and yet commanders worry about the flood of information. People may be spending too much energy on the volume, and not enough attention on what is flowing.

- Generalization period: Advances in technology eventually led to weapons which were lower in cost, imposed less demands for support and could be more easily carried on a wider variety of platforms. Beginning in the 1980s, this was the period in which unguided bombs were modified by attaching fins and adding guidance based on solid state inertial navigation systems (INS), the Global Positioning System (GPS), terminal sensors and algorithms (e.g., radar and IR), and combinations of these. Missiles such as ATACMS, JSOW and JSSAM appeared that could engage targets at extended range, and there was a proliferation (into the 2000s) of smaller weapons using various sensors to meet the needs for precision (e.g., terminally guided submunitions). In the 2000s the first major conflicts occurred in which precision munitions provided a greater percentage of air delivered ordnance than unguided bombs.[52]

- Next Generation: For much of the period since the 1960s there has been efforts to develop entirely new approaches to executing precision strike, such as through lasers, high powered microwaves (HPM), very high velocity projectiles, and cyber attack. These have been largely R&D endeavors and with a few exceptions have not yet appeared in the force structure.

The doctrinal and institutional support for precision strike can be traced to 1920-1945 and the emergence of strategic bombing. The literature of that period has referred to such bombing as "precise" (even in the face of the inaccuracies seen in World War II).[53]

- Consequently, one could argue that the doctrine and organization for precision strike have been in existence for over a half century. The obstacles to its achievement have been in the development of technologies to accomplish it and in the modification of existing forces to the extent necessary to implement those technologies.

- Alternatively, one could argue that advances in technologies beginning in the 1980s changed the costs of precision weapons, led to a variety of weapons for different uses, and altered the supporting military activities needed for their use (e.g., ISR and C2). Doing so led to an RMA, because these changes reshaped the concept of conducting attacks and changed organizational practices. Targets could be struck which previously might have not been feasible; delivery systems

[52] A rough count of the DSB's publicly reported studies shows that about 2-4 studies in 1990-1999 dealt with precision strike. In 2000-2010 the number was 15-20.
[53] As Watts and others have pointed out, the Army Air Corps believed in the importance of hitting targets accurately from the air, and even invented an artificial mathematical set of calculations to demonstrate (incorrectly) the effectiveness of aerial bombardment. Following World War II, the abstract commitment to precision was to some extent set aside by the introduction of nuclear weapons. Its practical importance re-emerged in the mid-1960s, not in strategic but in tactical forces, and not in general use but for a narrow set of applications. Not until the 1990s did technology reach the point that precision strike could be broadly used by U.S. forces.

achieved so great an increase in effectiveness that new employment concepts could be developed; "attacking" was no longer divided up among the military services as in the past; and, the military could alter some basic aspects of its approach to war. Finally, enemy forces were now vulnerable in new ways, and they in turn had to reshape their own method of fighting.

The first perspective views PS as a continuation of ideas from the early part of the 20th Century. The second views it as a new RMA. This analysis only focuses on the temporal aspects of precision strike, not on the resolution of these alternative views. The chronology at Tab 5 identifies a number of factors that have influenced that speed. [54]

Factors	Supporting Speed	Retarding Speed
Context	▪ Technology in the private sector provided underpinning for some elements of precision (e.g., solid state electronics, micro-processors, & solid state inertial navigation components). ▪ Other nations began making major investments in precision weapons.	▪ The commercial sector of the economy did not provide a broad base of related products. Precision strike has been fundamentally supported by DoD investment.
Problem or Opportunity	▪ In the 1970s various uses of precision weapons raised the interest in DOD and military services in precision strike, particularly the attacking of bridges in North Vietnam and the 1973 Middle East War. ▪ In the late 1970s the recognized threat to NATO of the USSR second echelon spurred interest in volume production of long range, low cost precision weapons to strike moving targets. ▪ In 1991 Desert Storm demonstrated the first large scale use --- and value of general use --- of precision strike. It also demonstrated the problems of doctrinal and operational differences between the military services. ▪ Conflicts since 1990 have demanded high level of precision. Its use in 2003-2009 only reinforced its value in	▪ The dominance of a threat of nuclear conflict with the USSR ---- and strategies for that --- focused SAC on nuclear delivery for much of the period from 1947 to 1990. SAC should have been the organization to adopt high volume, long range precision strike, but its attention was focused elsewhere. ▪ The limited number of strategically important targets in the Korean War, and in the Vietnam War diminished emphasis on developing a widespread capability to deliver precision strikes. Essentially, precision attack could be treated as a special type of operation, not a general one. ▪ The end of the Cold War diminished the seeming requirement for large scale conventional precision strike. NATO's defense against the second echelon was no longer needed.

[54] A table is used because actions and events do not all clearly support or delay an RMA. The list also demonstrates that speed is affected by many factors.

	combat where collateral damage and civilian casualties would have conflicted with strategy.	
Understanding & Potential Solutions	▪ In the 1980s the Soviets identified precision strike as an MTR; DoD picked up the concept in the 1980s; in the 1980s the Army and USAF signed onto coordinated doctrine for precision strike; and, it was incorporated into long range thinking by 1990. ▪ Precision systems in navigation, C2 and weapons in the 1990s blurred and then displaced doctrinal separation of roles between the USAF and Army. ▪ Concepts of intensity (targets per unit of time) and attacking the full range of enemy capabilities received increasing emphasis in the 1980s. ▪ In the 1990s precision strike was identified by the military services as a key element in warfighting. Wargames, exercises and analyses supported its value in improving military effectiveness. ▪ The USAF in the 1990s began thinking of targets per sortie vice sorties per target. ▪ Precision strike was a recurring theme in DoD public strategy documents by the mid-1990s.	▪ There seems to be little evidence that the military ---- having experienced RVN ---- began forward thinking about long range precision attack until perhaps the 1970s. It appears to have required explicit experience (e.g., observing the 1973 War) or a major problem (e.g., countering the Soviet second echelon) to generate demands. ▪ Army doctrine as early as 1980 was largely silent on precision strike, other than seeing it as an important character of close in combat (e.g., obtaining first round hits in tank-on-tank exchanges). Long range fires were to be provided by the USAF (with few notable exceptions such as Lance, Perching and Nike Hercules used in surface attack mode). The Army's interest changed in the 1980s with the problem of countering the Soviet second echelon. ▪ The Army conceptually faced the problem in the 1970s that it had a "200 meter mindset with 3000 meter weapons". The tactics to exploit such ranges (e.g., in positioning them on the battlefield) were not developed as quickly as feasible. SecDef Perry was wrong in his emphasis on simulation; field testing was essential to such understanding. (Gorman 1994) ▪ While statements appear to support the next possible generation of precision strike (e.g., laser, HPM, railguns, hypersonics), there does not appear to be a continuity of thinking about how to proceed.
Organization Change	▪ The early USAF linked itself tightly to technology. It forecasted the potential role of laser guided weapons in the 1950s, tapped the Army's development of the technology in the 1960s and contracted for systems by 1970. ▪ Beginning in the 1980s the technological capabilities for precision strike undermined the traditional separation of roles	▪ The changes to precision strike have grown the numbers of people who can designate targets and organizations who can do so. Expansion has gone from staffs and pilots to officers in C2 centers, to enlisted personnel in the field, to UAV pilots in CONUS. Moreover, the number of planned targets has declined and those that are ad hoc have climbed. Organizational practices have been slow to adjust, often making major changes as the

	between the Army and USAF. Up to that point geographic dividing lines (e.g., Fire Support Coordination Line) separated what each service could do independently. By the 1990s the Army could strike deep with MLRS and ATACMS, and the USAF could engage targets very accurately near troops. Doctrine and practices changed. ▪ The USAF in the 1980 began establishing squadrons for systems specifically created for precision strike (e.g., F-117 & JSTARS.) In the 2000s the USAF established UAV units, and then assigned them roles in attacking targets with precision weapons. The Army in 2003-2010 began widespread use of UAVs, and then armed them for precise attacks. ▪ In 2003-2010 DoD bypassed its acquisition processes to accelerate incorporating precision strike systems into the military.	result of exercise and combat. ▪ In the 1970-1990s DoD acquisition practices made the employment of sensors and weapons for precision strike a process that incurred decade long timelines between R&D and fully fielded systems. ▪ The Air Force did not embrace precision strike as a general practice until the 1990s. For example, in the 1980s the ability to use INS to improve unguided weapons could have been implemented but SAC was not interested. A few specialized bombs were developed for the B-2 by the late 1990s, when they could have been available as much as a decade earlier. For TAC the potential of LGBs was aside for much of the 1980s because of commitments to dive bombing.
Equipping Forces	▪ In the 1960s, laser technology and systems led to precision weapons, but technological limitations affected cost and widespread operational use. ▪ In the 1970s DoD developed long range conventionally armed cruise missiles using new guidance and navigation technologies. Beginning in the early 1980s, the Navy installed vertical launch tubes in the thousands on surface ships to carry tomahawks (and other missiles). ▪ In the late 1970s DoD led technology developments to attack moving targets in deep areas. ▪ By the 1990s solid state INS and GPS lowered costs and moved off-board certain functions, leading to mass production (and thus wide use) of precision weapons (e.g., JDAMs).	▪ The high cost of precision guided missiles (e.g., Tomahawk) in 1970s limited use of precision strike to special circumstances. Arms control agreements limited the use of convention cruise missiles on certain aircraft. ▪ Advanced avionics on manned aircraft in 1980s (e.g., the F-16) appeared to provide precision strike without having to employ guided weapons. This delayed widespread use until SAM threats in the 1990s pushed aircraft to higher altitude release points and accuracy degraded. ▪ Contractor failures to deliver low cost precision guided weapons and terminal munitions in the 1980s and 1990s delayed broad use. ▪ Precision strike has placed major demands on systems for surveillance, targeting, damage assessment, strike planning, etc. For example, individual targets need more data (e.g., precise location, collateral damage risk,

	▪ In 2003-2010's conflicts a proliferation of technology and system changes provided a variety of weapons and supporting C4ISR systems for precision strike.	hardness, linkage to enemy capability) and more rapid updating of data. For example, in Desert Storm F-117 and F-111Fs hit aimpoints in nuclear facilities within 8-10 feet 80% of the time. These were unsuccessful because the nuclear program was not well understood. (Watts Sep 1993)
Developing Personnel	▪ Combat experience in 1990-2010 has led to greater practical skills among officers and enlisted personnel in implementing precision strike. ▪ In the 2005-2010 period the USAF trained UAV operators to attack targets with precision weapons.	▪ The perceived importance of dive bombing to pilot status delayed wider adoption of precision strike in 1980s.
Top Level Support	▪ Senior civilian and military leaders have been endorsing precision strike concepts and systems since the 1970s. ▪ Leaders have developed and supported concepts such as DBA and NCW in the 1990s, in which precision strike was a major feature. ▪ Top level planning documents in 1990s-2000s (e.g., the NDP & QDR) have supported precision strike and linked it to systems.	
Allocating Resources	▪ Combat in 1991-2010 has resulted in commitments of funds to developing precision strike systems.	

The chronology suggests that many factors have played a role in the speed of this RMA:

- Problems, threats, and external pressures came from several different directions. Initially it was --- in Vietnam ---- how to attack hardened military targets in well defended environments where conventional air attacks were largely unsuccessful and were costly in aircraft and pilot losses. In the late 1970s the problem was avoiding defeat in NATO when the large Soviet second echelon would arrive at the FEBA and overwhelm NATO forces.[55] In the 1990s the problems of regional

[55] While JSTARS and related weapons receive major attention in histories, this was also a period in which the USAF attempted to deal with Soviet forces in deep areas with its current weapons. One problem was overcoming Soviet air defenses. Part of the response was to develop new standard EW protection packages for aircraft that could be reprogrammed with software to counter ever changing threats. Another was to devise systems to locate enemy air defense radars (PLSS – Precision Location Strike System), and vector attacking aircraft (QSR – Quick Strike Reconnaissance).

conflicts, counter-terrorism, trans-national enemies, and peacekeeping led to demands for high accuracy in order to win without destroying a nation's economic and social structure.

- In parallel with these external factors technologies emerged that facilitated ---- or even encouraged ---- refinements in precision. LGB technology had lessened the risk to aircraft and improved their effectiveness, but had limitations (e.g., requiring clear air, and demanding special systems such as laser designator pods). But in the 1980s-1990s major changes in solid state electronics and navigation made precision less expensive and more readily added to platforms. [56] Also, the development of sensor technologies at the national and tactical level began providing the data that were needed to identify when and where targets were available.

- The first major conceptual steps appear to have occurred in the 1970s, and largely among civilians, not the military. Today it is curious that the DoD's public strategy and planning documents include sections that prominently features information warfare, but do not accord similar emphasis to precision strike. That may indicate that precision strike is so universally accepted as a military practice that developing unique concepts of operation are not required; precision strike is just incorporated into concepts for a particular force or for a particular operation. On the other hand, such focused concepts may be required if precision strike moves into the new generation of attack technologies.

- Organizational changes to apply the concepts of precision strike seem not to have occurred on a large scale, except in the formation of units for the major systems (e.g., creating squadrons for JSTARS and UAVs). One could argue that major unit restructuring was not in fact necessary. Precision strike was a capability that could be absorbed within the mission and structure of existing units (e.g., B-52 units had a conventional role, and the F-16 could carry precision weapons). [57] Moreover, precision attack was as much about the linking together of organizations and practices as it was about creating new combat units and dispensing with old ones. It involved a large amount of integration across

[56] In the 1960s the electronics in munitions such as LGBs were bulky, expensive and sensitive to handling, shock and weather. LGBs also used only one sensor. By 2000 the precision component of munitions could be the size of a large fruit can, include multiple sensors (GPS, IR, EO, MMW), and include the computer processing to identify the place on the target for the munitions to strike. The introduction of guidance packages involving multiple sensors enabled aircraft to drop the weapon and depart, whereas LGBs required an aircraft to linger over the area designating the target.

[57] For example, according to Watts TAC's more vigorous adoption in the 1980s was partially delayed by the cultural commitment to dive bombing and technical improvements in the avionics of the F-16 providing increased accuracy. SAC was a nuclear strike force from its inception through the 1980s, with only limited applications of conventional attack. It was not until the 1990s that precision weapons began to become a major part of the weapons to be carried on the B-52, B-1B and B-2.

systems and organizations in ISR, C2 and combat operations. Processes and not new units may be more prominent factors in organizational change.[58]

- Desert Storm provided the first large scale and highly visible examples of using precision strike on a broad basis. It was an intermediate benchmark that demonstrated the potentials and identified the problems of precision strike.[59] Ten years later --- with new precision weapons (e.g., JDAMs), improved sensors and improved C2 systems ---- precision strike systems were to be greater than 50% of munitions delivered by air.[60]

As to the speed with which precision strike has been adopted, the wars of the past 20 years have provided a major stimulus. What has perhaps slowed its adoption has been:

- The acquisition practices of the DoD and the quality of management of companies: A number of technologies and systems were late in their introduction for a variety of reasons, many having less to do with technology and more to do with acquisition and project management and engineering skills.[61]

- The absence of vigorous continuous leadership for precision strike: While leaders are credited with emphasizing its importance, no one person or set of people emerge as continuing visionaries, advocates and implementers.

- As in IiW the breadth of precision strike: It has involved multiple military services and multiple platforms and systems. It has involved multiple missions and goals of military organizations. It has blurred distinctions between tactical and strategic, between Army and Air Force, and between service and joint. Its

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[58] For example, precision strike changed the use of geographic boundaries to separate Army and USAF operations, and increased the need for processes to coordinate fires. The Army and Air Force signed an agreement in the 1980s to develop capabilities in parallel to deal with NATO forces. Frequent references to the role of the Black Hole in Desert Storm and to the inadequacy of the ATO process are indicators of the process needs.

[59] It probably helped that Desert Storm ---- while replicating a NATO/WP kind of war ---- was an unequal fight in which the military outcome was never at serious risk. Allied forces never faced major destructive threats that would have stressed the concepts of precision warfare. It also helped that the DoD and the U.S. military studied and wrote extensively on the Desert Storm experience. Indeed, Desert Storm appears to be one of first major conflicts in decades in which the U.S. extensively analyzed its own performance. That accomplishment may have been instrumental in changes in the 1990s that improved fighting effectiveness in 2001-2009.

[60] The change was not just in volume of precision weapons but in the manner of their employment. Watts points out that about 20% of Desert Strike sorties were retargeted after launch. By 2003 that was over 90%. The targeting cycle that was measured in days in 1991 was down to 12 minutes in 2003. (Watts pg 277)

[61] JSTARS, for example, took 27 years to field. Part of the problem was technology and fear of enemy SAMs. Part was not understanding the value of blobs on radar screens. Part rested on the testing bureaucracy, which pulled JSTARS back into testing even after its proven success in Desert Storm. (Fowler 1995)

> progress has been highly dependent on technologies at fundamental levels (e.g., solid state electronics), functional levels (e.g., navigation) and network levels (e.g., C4ISR). DoD as an organization has difficulty integrating at such levels of complexity.

A speculative question is how precision strike will progress in the future. Having been established as a common practice it may need no further pressures. However, if it is moving in the direction of entirely different attack mechanisms (e.g., lasers, HPM, railguns and hypersonic missiles), these may be such a departure from the existing weaponry of combat units and combat practices that they will require substantially more attention by leadership and in exercises, doctrinal developments, etc. Otherwise, the military --- while actively supporting precision strike ---- may inappropriately try to incorporate these into its existing operational concepts and units. In other words, this RMA may enter a new cycle which will require the kind of radical changes that analysts generally associate with an RMA.[62]

[62] Another way to examine this next phase could be to view it from the perspective of military operational problems to solve. The history of precision strike is largely about the need to meet needs to attack targets that are unassailable or almost unassailable with the older methods --- e.g., they are hardened or heavily defended, moving, moving in large numbers, located at very long ranges, or present risks of collateral damage. The question is what could be the future sets of unassailable targets ----- e.g., deeply buried ones, attacking nuclear and chem.-bio targets without releasing contaminants, solving new restrictions on collateral damage (e.g., take out a piece of a satellite), or striking at great ranges near instantaneously?

Observations on the Current RMAs in Precision Strike and Information in Warfare

On balance these two RMAs had been reasonably successful by 2010.

- Precision Strike: This method of attack had become a widespread aspect in the use of military forces, and a common requirement for weapons and platforms being developed for the future. It had become a recurring theme in policy and strategy documents. Still questionable by 2010 was whether enough changes had occurred in military organizations and processes, and whether the current approach of inserting capabilities into existing units would be appropriate when very different technologies (e.g., hypersonics, lasers, etc) were introduced or very different military situations were encountered (e.g., employing precision strike in space or in intercontinental ballistic attack). But in general precision strike had become a major component of contemporary warfare.

- Information in Warfare: IiW had also become a major element of policy and strategy, from the level of the White House to the tactical forces in the field. The distribution of information even to the level of soldiers had been growing constantly. Organizational changes had been made at the joint, DoD, and military service levels. As with precision strike IiW had become imbedded in the thinking and actions of the military, at the level of functions (e.g., logistics), operations (e.g., joint forces) and military strategy (e.g., IW). On the other hand, a more sober assessment of progress might emerge if IiW were examined in specific functions, missions or strategies. Moreover, organizational barriers to sharing were still being reduced; it was unclear that future major new areas (e.g., cyberwar) were being adequately developed as RMAs; and, more attention was probably needed to understanding the value of additional information as opposed to just acquiring and distributing it.

Depending on the start dates one wants to select, it appears that the speed with which these RMAs progressed was not appreciably different from RMAs in the interwar period. Precision strike can be traced to the 1960s and underwent major growth beginning in the 1980s. IiW followed a similar path, starting in the 1950-1960s, and accelerating in the 1980s. This suggested timelines of 30-50 years.

Ideas of how each RMA could have been accelerated have been mentioned in the previous section. Several general points need emphasis in considering speed.

<u>These RMAs began and then progressed in the midst of building the first large peacetime permanent organization for national defense in American history.</u>

These RMAs ----- tracing their origins back to the 1950s ---- occurred during the establishment of the DoD and the emergence and involvement of the U.S. as a major power.

- For the first time in American history there was a large standing military and civilian work force.[63] The structure of the national security apparatus changed dramatically, with the formation of the USAF, the establishment of one cabinet department, and the formation of a joint command structure. A number of defense agencies were established. Common management practices were installed to accomplish strategy development, planning, budgeting, accounting, and procurement.

- For much of the period the U.S. faced one major great power opponent, and since 1989 potentially has been facing different types of emerging competitors (e.g., China or resurgent Russia). The U.S. military has had to think about, prepare and conduct many kinds of warfare (e.g., counter terrorism, pacification, limited precision attack, general conventional war, and nuclear war). Conflicts and crises may occur relatively quickly, and the importance of early and significant military action may prevent the U.S. from relying on gradual involvement while mobilizing military and industrial capacity.

Size and commitment can be of mixed blessing. Organizational size on its own is a detriment to speed, and requires special management focus to overcome. However, large organizations can muster the resources for large endeavors, and the commitment of the military to various deployments can provide the pressure to encourage replacing outmoded means of fighting or deterring. One could probably argue that pressures to attack the Soviet second echelon, Desert Storm and the wars in Iraq and Afghanistan accelerated the U.S. military's pursuit of these two RMAs. On the other hand the demands of current operations can reach a point at which they diminish the transition by diverting individual, organizations and resources to pressing near term needs.

In considering the future there could be several areas for concern:

- The breadth of potential challenges to the U.S. --- in contrast to the interwar years ---- raises questions of how to link RMAs to the range of possible conflict or deterrence situations. In the interwar period the RMAs dealt with a relatively small number of threats or opportunities. Today the variations seem much

[63] At its peak of 2.1m personnel in the Cold War the people in uniform were five times larger than in 1930. Its civilian workforce grew from under 200,000 to 1.2 million, and then in the 1990s declined to over 800,000. Officers came more from universities than from the two (and later three) military academies. Enlisted ranks, especially after the creation of the all volunteer force, became even more highly skilled. The civilian work force also changed as development and manufacturing moved from public facilities to private firms. In the past few decades even management and administrative skills moved from the civil service to the private sector.

greater. Will any implementation path in an RMA --- or set of RMAs --- provide solutions to the diverse challenges facing the U.S.? If not, then what are the subsets of RMAs useful for each class of challenges? [64]

- The range of challenges --- and the difficulty of predicting them --- may mean that thinking about RMAs should move from the specific (e.g., long range strike) to the general (e.g., building leadership in IiW). Rather than try to predict a particular threat, it might be better to predict underlying commonalities across many threats. One could argue, for example, that focusing on developments in sensors for the last few decades as part of IiW built a capability that was then applied to the particular problem of IEDs. Rather than try to predict a specific threat such as IEDs, it may be more constructive to predict that sensing the enemy environment will be a common challenge in combat environments. If so, then the task in contemporary RMAs is to understand where the next major breakthroughs could occur in the underpinnings of how a military fights.

- A culture of civilian management of national defense has evolved. This can be traced to such actions as Eisenhower's use of the NSC system, McNamara's changes in the 1960s, the emergence of think tanks that led thinking about various forms of warfare, and the rise of national security studies programs in universities.[65] A potential problem is the senior ranks of those civilians can become largely political rather than managerial in their focus, and the lower ranks can become largely bureaucratic and not mission focused.[66] Neither set would

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[64] China, for example, is more tightly woven into world affairs and more linked to the U.S. than the USSR ever was. What types of RMAs are important? Additionally, great power competitions may occur in a manner so that the U.S. is not on center stage or only part of a multi-player competition (e.g., Russia-China or India-China). How should the U.S. pursue RMAs in such complex situations?

[65] Andrew May's dissertation on Rand describes the internal debates over the best approach to nuclear war strategy in the 1950s. As he has noted this was largely among civilians; indeed, Hap Arnold set up Rand even before the USAF was established to conduct this kind of thinking. Also, in McMaster's critical analysis of leadership in 1963-65 on Vietnam he states "McNamara …. believed fervently that nuclear weapons and the Cold War … had made traditional military experience .. not only irrelevant, but often dangerous for contemporary policy ….. (He) and his staff …. (believed) that military officers took too narrow a view and based their advice on antiquated notions of war". (McMaster pg 326 & 328) One could argue that in the twenty five years from 1945 to 1970 the appearance of a new form of war (i.e., nuclear), two failed conventional wars, interservice rivalry and the establishment of a DoD permanently diminished the militaries' claim to leadership in formulating strategy, operational concepts, and maybe even tactics. Unfamiliar with having a major role in strategy (other than in wartime) it was simply overrun by the changes in the several decades following World War II. Moreover, in that same post-World War II period, universities in their entrepreneurial way jumped on the issues of national security and began producing graduates that then both populated and created career fields in national security analysis.

[66] Civilians --- much like their military counterparts --- also seem to lack the presence of named individuals who provide determined leadership of new concepts (including providing for continuity of support after their departure).

see itself has having a major responsibility for strategy, even though they now arguably control strategy.[67]

- DoD is no longer a new institution, but a set of organizations with established practices for daily operations. Critics comment that it has become overly cumbersome and inefficient; a more positive view is that it has a track record of success in deterrence and conflict. It may not fight every crisis or conflict in the optimum manner, but it does well enough. The concern, however, from an RMA point of view is that it may not be able to respond or compete adequately if the underlying characteristics of international competition change substantially. As noted elsewhere, for example, what happens if speed of adjustment becomes a strategically important element of international military competition?

<u>The major characteristic of these two RMAs is the breadth of their impacts across the American military.</u>

These RMAs are different from the changes in carrier aviation, mobile armored warfare, amphibious operations or strategic bombing. They sweep across military forces and are hard to isolate to particular platforms or military department. They integrate multiple military services and agencies, link multiple platforms and systems, and change operational practices of military organizations in combat. They cannot even be isolated in geography to a local force or a theater (e.g., tactical information is processed in CONUS for immediate use in Iraq; people in California drop bombs on individuals in Afghanistan.)[68]

The successes of IiW and precision strike demonstrate that obstacles to such broad reach across organizations and combat environments have been at least partially overcome. The pressures of combat operations have led the military --- even at the lowest levels --- to develop ways to coordinate their operations, and the military ranks have demonstrated an ability to absorb and use new technologies and systems (demonstrating once again the value of a smart military that is well educated, endorses initiative, and trains). Management practices have been modified to overcome impediments to quickly equipping military forces. Technologies have provided increasing connectivity among systems and military forces (in addition to providing improved components and subsystems).

[67] The current QDR, for example, has been criticized on several grounds --- that it had to be edited so that China would not take umbrage, and that it was largely a confirmation of budget decisions already made. Both suggest politics take precedence over strategy. It may be that there are comprehensive non-public strategy discussions and policies, and the civilian leadership is deeply and insightfully involved in defense strategy. The public record does not seem to show that..

[68] People have pointed out that the RMAs of the interwar period were largely about platforms around which people could rally. These RMAs are less well coupled to specific platforms and more to how they are tied together.

Looking to the future there are several major areas for concern:

- The importance of integration and the role of technologies in accomplishing it are now widely available among many nations. This is now an area of competitive advantage for the U.S., not absolute advantage. The strategy documentation does not seem to give sufficient attention to how that competitive situation affects U.S. strategy in these RMAs. The documents appear to focus on the threats, but not on more subtle issues such as using these RMAs to sustain advantage.

- The use of speed as a strategic tool is an important element of that competition. This is not "speed" in the sense of equipping the military force, but speed in strategic terms of either keeping ahead in key areas, or insuring the rates of change are greater in the U.S. than in an opponent's military. Speed is mentioned in documents as a character of the underlying technologies (e.g., Moore's Law) or as an operational issue in combat. But there seems to be little attention to speed as a strategic element of the competition. Moreover, DoD may be treating the need for speed as a temporary and more tactical phenomena (e.g., accelerating equipping forces for Iraq and Afghanistan), one that will lapse when the current conflicts end.

- A gap may exist between support of these RMAs in strategy documents and top leadership, and disciplined follow-through to developing concrete concepts of operations and implementation. There have been criticisms of the lack of speed because of bureaucratic resistance, process breakdowns and lack of comprehensive joint doctrine. [69] One could argue that the two RMAs have been absorbed over time through combat and other experience, even though a body of concepts that traces through to organizations, people and systems does not seem to exist (it is more fragmented). [70] This would account for some of the delays so far; more interesting is how it may affect both RMAs in the future if they move in very different directions.[71]

[69] The USAF is considered by some not to have much content in its written doctrine on fighting at the tactical or operational level; its changes are viewed as coming about by gradual movement of its constituent "branches" (i.e., TAC, SAC, MAC). The Navy is similarly seen as viewing doctrine as what is practiced rather than what is written. The Army, while the most prolific of the services in writing doctrine, appears to struggle bureaucratically and intellectually with the issue. The joint level --- as with the Army --- focuses major efforts on the process of developing doctrine, and frameworks for doing so. It is questionable whether the focus on process and frameworks tends to cloud clarity about major choices on the content of operational art.

[70] Moreover, some have noted that in the interwar period the daily work might be done by mid-afternoon. Contrast that with the long work hours of Pentagon assignments, combat units in peacetime bases, and especially in combat assignments. There may be little "slack" time for people to engage in major change.

[71] However, it should be considered that, as difficult as it may be for DoD, the task of integration may be even more difficult for opposing states, lacking the depth of practical wartime experience. Organizational skill in other words could be a source of competitive advantage. Overall, the American military has more practical combat experience in IiW and precision strike than any potential opponent.

- Pressures for integration across militaries and agencies may ---- if not carefully watched ---- reduce the rate of innovation and change in these RMAs. Militaries and civil agencies have pursued different technological and operational approaches in IiW and precision strike over the past decades, sometimes in direct competition and sometimes in believing different approaches offered more promise. However, there has been increasing emphasis on standardizing on specific systems, and increasing criticism of duplication in programs. Can a balance be struck between the seemingly logical imperative to standardize and the need to sustain competition in order to support innovation?[72]

- DoD seems inherently weak in managing integration. DoD has been repeatedly criticized, at the level of civilian agencies, military services, the JCS and staffs in general for cumbersome and less than effective processes.[73] DoD seems to cling to old practices (e.g., consider the inability to implement changes in acquisition practices despite over 20 years and 100 studies of the subject). Complex integration across large organizations requires constant top level attention and an appreciation for the intricacies of implementation. Neither seems present in DoD.[74]

The joint nature of these RMAs --- while improving military effectiveness --- has added an overlay of relationships that in general can add to the time element of developing the RMAs.

<u>Technology is more complex and has more impact on the speed of these two RMAs than in the interwar period.</u>

Analysts agree that technologies and systems are much more complex on almost any level than in the interwar period. Platforms, subsystems and components involve more complex designs and tradeoffs. They involve more complex linkages of different

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[72] DoD's past approaches permitted the centralized development by ARPA of packet switching, Arpanet and thus the internet. But it also permitted the diversified development of ISR processing systems in different agencies and military services, including competing designs for processing ISR information. Competition encourages exploring different technologies and applications, particularly important when the success of technologies cannot be predicted beforehand.

[73] For example, at the level of OSD there appears to be strong separations between those who set funding levels, those who develop and acquire systems, and those who set policy and strategy. And, only in a few areas are there organizations that integrate across these to support a specific mission (e.g., in special operations). No organization appears to be focused on integrating for the purpose of advancing RMAs. As some analyses in the chronology on IiW noted, there is a wide gap between issuing policy statements and actually implementing actions.

[74] As mentioned earlier the German's actions in 1918-1926 present a textbook example of managing major change in an RMA, and many of the actions are the type favored in current management research. In these current RMAs there are few examples of actions such as named individuals leading the effort, continuity of leadership, leadership involvement in greater depth than policy statements, leadership attention to positioning people, etc.

technologies and systems.[75] Their underlying elements are more diverse (e.g., mixing materials technology, software, and solid state engineering).[76] Manufacturing is more capital intensive than labor intensive and requires more engineering and development in techniques, tools and processes.[77] Automation has altered system approaches and provided tools to improve selection among alternatives in design, development, production and support.[78] A "systems of systems" approach appears to characterize most candidate RMAs of the present times.[79]

Technology imposes its own time delays. It takes time to develop the intellectual engineering infrastructure. Big systems and integrating many systems in networks takes time to accomplish (even discounting delays from mistakes in estimating the scope and schedule of such projects). Within the time periods the technologies themselves change in fundamental ways and alter the nature of the original projects. In addition the rules and processes for developing technologies and systems have built-in time delays. Prototyping has been shown to add to the time it takes to bring a system to the field (demonstrating that prototyping is not associated with accelerating acquisition but with controlling for other factors such as cost, performance and risk).[80]

[75] "The products of the … (DOD) … are perceived as becoming increasingly complex, emphasizing multifunction and multi-mission system configurations. Such weapon systems utilize network capabilities and systems of systems engineering and integration methodologies throughout their life cycles. The management and oversight of these complex programs have similarly become more complex." Recent research has concluded that complexity of systems has increased over time, as measured in the number of interactions among subsystems, degree of integration among subsystems, and degree of integration at the component and part level. (Drezner in Ben-Ari pg 31, 33)

[76] Just consider the amount of study in universities required to position people to begin to work in the different fields of engineering and science, the granularity of advances (e.g., nanometers, formulas for composites, signal processing) and the technical challenges of linking systems (e.g., interface standards, protocols, message formats, routing technologies).

[77] For example, in solid state components (e.g., microprocessors, sensing devices, and radar transmit receive modules) the design of the component must proceed in parallel with the design of the manufacturing operation.

[78] Automated tools changed processes, from analyzing the military effectiveness of ideas to producing systems. Digitization, software and hardware have enabled the military to reduce the number of potentially successful designs before building prototypes; to test the impact of designs on operational effectiveness; to reduce the number of prototype systems to be tested while increasing the data drawn from such tests; to rapidly compare design ideas against their producibility; and, to then translate designs into tool instructions. None of this existed in 1920-1940.

[79] Some examples of SOS appeared in World War II (e.g., British air defenses). The broader growth began in the 1950s with continental air defense (e.g., SAGE). In subsequent decades SOS appeared in missile warning (e.g., BMEWS & DSP), battlefield air control (e.g., AWACS), standoff ground attack (e.g., JSTARS), missile defense (e.g., Stars Wars), and space awareness (e.g., Spacetrack, Cobra Dane, & BMEWS).

[80] Attempts to collapse those time factors --- through concepts such as concurrent engineering or setting aside rules for sequential actions ---- have encountered significant resistance. Even the Packard Commission in 1986, for example, recommended there be no full production until a system had completed operational test. See Drezner, et al for an excellent analysis of how aircraft programs have lengthened in time since the 1950s.

Looking to the future there are several major areas in technologies and systems that will affect speed.

- Network architecture in the past forty years has been largely associated with communications, and only in the past twenty has the concept of "architecture" broaden to the level of "systems of systems". One could contend that the resolving the complexities of developing technological solutions, design principles, etc. for "systems of systems" is still in its formative stages. The question is whether DoD is adequately supporting that development. And, has DoD examined how to maintain a competitive advantage over other nations in that discipline?

- In very complex systems it is difficult to understand beforehand their full structure, their flows, and how they might be used.[81] For example, system wide failure can come from unanticipated events, and small component failures can have non-linear impacts.[82] Some people believe that this can be overcome through simulations; others believe that comprehensive exercises are needed. Even then, the actions of junior enlisted and officer personnel in the current combat zones suggest that actual use is important to fixing problems and evolving new ways to use technologies. The question is whether the DoD approach to simulation, prototyping, exercises, combat operations, etc. provides for early detection of the prospects and problems of systems of systems.

- DoD's organizations is the impact of its acquisition and management practices exert a strong influence over the pace of change. There is no research on specifics aspects of those processes and their affects on RMAs.

- While military personnel are adept with using new technologies in their units, the question is whether the military is developing enough technical skills among its officer and enlisted ranks to be able to effectively shape the emergence of systems, their integration, and the development of operational concepts and

[81] For example, when ARPA developed the internet they found engineers inventing games to play on a countrywide basis in the U.S., and had to setup controls to prevent software engineers from tinkering with the network's interface processors. Systems of systems can also provide unanticipated benefits. For example, JSTARS --- in addition to its basic mission of locating deep enemy forces --- also detected in real time the location of friendly units and the outline of their forward position. It thus became a C2 tool as well as an ISR and targeting tool.

[82] For example, a software problem caused the bomb damage assessment information system to collapse in the first hours of Desert Storm, and fixing and rebooting took time. And in the 1970s the USAF tested a collection system in Europe that produced dramatic increases in combat message volumes; the messages were transmitted through common user communications to combat commanders and were accorded top priority. However, the switches in the communication network had been designed to halt and store lower priority traffic to pass the highest priority messages. The volume of these new messages caused the switches to cycle so much between storing and recalling messages from its buffer that the overall network degraded.

strategies. An example of this problem is the continued setting of unrealistic performance requirements for the cost and schedule of new systems. The interwar RMAs suggest that the evolution of an RMA is more effective when the military ---- especially its leadership ---- understands the technologies well enough to understand their impacts on warfighting at the strategic and operational level (not just at the tactical level).[83]

- Major named personages in science and technology seem to have been more commonplace in national security strategy development in the 1940-1960 period than today.[84] Is the government adequately tapping the right set of outside people for a future national security environment that seems to be highly dependent on technologies deeply imbedded in the commercial sector and spread on a worldwide basis?

- The chronology suggests that ideas for new force concepts can emerge as much from civilians as from the military. For example, the DSB 1996 Summer Study recommended a new warfighting approach integrating technologies in IiW and precision strike. That study's recommendations also identified key steps that resembled the list of factors affecting the speed of RMAs listed early in this report.[85] Is the department continuing to emphasize such research? Should it be applying and organizational approach of the DSB to the JCS?

- Skill in integrating multiple systems requires a mix of formal education and practical experience. A crude indication of this is the general belief that the common characteristic of good system architects is that they are over 40 years of age, i.e., they are trained by trial and error as much as by academic learning (much like airplane designers of 1920-1940).[86] Both government and industry have stated that this pool of people is shrinking.

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[83] The same criticism might be directed at civilians, for possibly having a better understanding of the technologies but less understanding of warfare.

[84] Eisenhower was instrumental in creating the emphasis on technology in his tapping of civilian scientists and engineers for advice, in creating government technology organizations (ARPA, NASA), and in supporting major technology initiatives (e.g., ballistic missiles, nuclear powered combatants, high performance aircraft, and satellites). Since 1980 the names associated with outside advisors do not appear as prestigious as in the middle of the century. It may well be that by 1980 working on national defense --- for new creative challenges, for opportunities to contribute to the nation, etc. --- had become less attractive.

[85] The report mentions steps such as "dedicated joint effort", "extensive simulations", "red teaming", "field experiments", "technology demonstrations", "firm commitment and support from the top", and "establish a joint effort". It also notes that "there is no ideal home within DoD for the exploration of something both as new and as intrinsically joint ……. While a CNC leadership would bring the joint perspective, the Services are better positioned today to start running with this concept." In other words, in the mid-1990s some people already could believed in the potential revolutionary impact of IiW and precision strike, and the inability of DoD's joint structure as an organization to exploit it. (DSB 1996 transmittal letters)

[86] This not a criticism, but just a belief held by many. Major improvements have and continue to be made (e.g., in the capacity to simulate network architectures). It does, however, parallel the observation made by Gladwell and others about "10,000 hours". Studies of experts in various skills (e.g., musicians) indicate

The private sector and its industrial base have a major role in these current RMAs.

This private sector involvement includes not only the industrial base of technologies and systems but also the intellectual impacts of academic, private analytical, non-profit and advocacy institutions. In technology and systems they have been a principal source of the advanced systems in these RMAs.[87] They have also provided the intellectual engineering substructure (i.e., educational programs, fundamental research, development of design principles, etc.)[88] Moreover, unlike the interwar period these private sector organizations have influenced strategic thinking and military operational thought.

However, this has also created a new set of interest groups in national security that influence choices in technologies, systems and strategies and thus affect the emergence of RMAs. The non-profit organizations, think tanks, universities, and federally funded research organizations have created analyses, conducted R&D and lobbied for points of view. Defense firms have become a major source of jobs and political influence.[89] These firms on occasion can exert more control on the military than the military can exert on them.[90]

This industrial setting has been changing in significant ways in the past several decades. First, the technical knowledge for building complex military systems has spread to the industries of many nations. For example, satellite surveillance systems are now widely developed; advances in sensor technologies have been emerging in foreign states; and, micro-electronics design and manufacturing is often located overseas. Second, the American defense industry has become increasingly concentrated at the prime level, is

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that roughly 10 years and 10,000 hours of concentrated effort are what differentiates them from very good but not the leading people in their fields.

[87] In the 1950s the government was the major source of R&D investment, and it resulted in numerous advances in electronics, computers, software, communications, etc. Commercial R&D grew substantially in the following decades. One of the criticisms today is that the large laboratories that firms self-funded in the 1960-1980s have been sharply cutback by the intense attention to earnings and the resulting drive of managers to insure that R&D projects are focused on eventually successful products. Who will fill the gap in exploratory research is a question.

[88] See Hafner for a story of the internet, Campbell-Kelly for the history of software and Saxenian for the development of centers of technology culture.

[89] This problem has become more severe in the recent decades in Congress. The economy is now both so large and so complex that legislation can appear to local voters as somewhat vague in directly benefiting them. Defense spending is one area where Members can see --- and claim --- a direct impact between their actions (e.g., keeping a production line open) and jobs in their districts.

[90] For example, in the 1990s the Navy attempted to build a new surface combatant. Wanting to focus on systems and not hulls it forced the creation of two competing teams in which the prime contractor would not be a ship builder but an integrator. Shipbuilders would be a supplier. One team then refused to bid (potentially creating a sole source award), telling the Navy it knew the Navy would eventually come to preferring a shipbuilder and its team had none of the favored Navy builders. The Navy was forced to amend the procurement. The other team then refused to compete and the Navy had to again redesign the acquisition plan. Finally each team received several hundred million dollars to develop a design. Several years later the Navy cancelled the entire program after several hundred million had been spent.

consolidating at lower tiers and some firms are exiting for the commercial market. The nature of competition and innovation has been changing. Third, the buying habits of the government have shifted from procurement to R&D, and from both of those to services. So the U.S. is facing a more skilled foreign industry and a restructured domestic industry.

Looking to the future there are several major issues that can affect the speed of RMAs:

- The reduction in the number of firms in different skill niches of the American defense industry has led to oligopolies and monopolies in many areas (i.e., certain types of aircraft, submarines, armored vehicles, etc.) In other areas the number of competitors has dropped dramatically and even surprised defense prime contractors.[91] While the DoD has increased attention towards sustaining multiple sources to maintain competitiveness, it unclear if this has been analyzed from the point of view of rates or progress in RMAs.[92]

- It is also unclear whether DoD personnel in general understand American industry and the defense industry as a subset. An indicator of this is the misunderstanding of the implications of the shrinkage and consolidation of the industry from 1985 to 2000, and the fact that the industrial base has not been part of national security documents until the last ten years. Even then the DoD's actions seem largely restricted to reacting to actions of the firms in the industry such as further attempts at consolidation.

The dynamics of the relationship between RMAs one the one hand, and the industry that supports technologies and systems on the other, do not appear to have been researched in much depth.

<u>The DoD appears to have lost interest in RMAs.</u>

From the record of meetings, conferences and studies the attention to RMAs appears to have peaked in the 1990s and then subsided. As noted elsewhere there are numerous analyses of RMAs in the interwar period but no matching body of analysis of those in the Cold War and post Cold War period. Watts' study of precision strike stands out if only because it appears to be the one example of such research. Absent that body of research

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[91] For example, the number of companies who would fabricate solid state wafers for DoD systems reduced from about a dozen to about half that number in the 2000s because firms moved plants overseas or stopped selling to defense companies because purchase volumes were too low. The wars since 2003 have provided indications that competition and innovation continue (e.g., UAVs, MRAPs, sensors). The question is whether this is a widespread phenomena in national security or confined to pockets of the industry where entry costs are not high and the current wars have generated both demands and funding.

[92] Moreover, there are many scenarios for the future of the defense industrial base. One of the more pessimistic is that the government and industry will move to a structure of monopolies managed closely by the DoD, a form of an arsenal system in which companies would become virtual government entities.

on the 1945-2010 period it is difficult to establish what expectations should be set for the speed or content of RMAs, or how to measure their progress.

Overall Conclusions and Hypotheses

The objective of this study was to examine the past record of work on the RMA to identify the factors the affected the speed with which RMAs progressed, and then to examine the history of existing RMAs to identify what was affecting their rate of progress. A hypothesis was that the RMAs of the current day seem to have progressed no more quickly that in the 1920-1930s. In considering the great differences between the time periods, why have the current RMAs not moved more quickly?

Studies of RMAs by various authors indicate that several dozen factors affect the pace of RMAs. No one factor controls the speed, and many are at work, often in relation to one another. Moreover, even though the interwar and the current periods are very different the same factors seem to be at work. Only their relative impacts seem to be different.

RMAs take 30-40 years to manifest themselves. The RMAs of the interwar period would have taken over 30 years, had it not been two world wars. Moreover, examining these RMAs in more detail suggest that they can move even faster (i.e., less then a decade). Two current RMAs --- IiW and precision strike --- also took over 30 years.

However, the research on current RMAs has been far less extensive than for those in the 1920-1930s. The RMAs in precision strike and IiW could be seen by 2010 to have been generally successful. Their origins can be traced to the 1950s in IiW (e.g., SAGE) and early 1960s in precision strike (e.g., LGBs). Major steps forward occurred in the 1980s in each (i.e., in developments in microelectronics, computers, software, algorithms and low cost multi-sensor guidance). Depending on one’s definition of completeness, by 2010 these RMAs can be considered as in the late stages of implementation or well into a lengthy change process. But certainly they were not struggling to survive, were widely accepted as essential aspects of warfighting (even in foreign states), and had resulted in changes to doctrine, organization and systems in the U.S. military. Indeed, they had reached many of these milestones by the end of the 1990s.

The question is whether this could have been achieved faster. A speculative answer is “yes”. How much faster is even more speculative. For these two RMAs the key start period for their current configurations is in the early 1980s, when the technologies began providing the groundwork for the scale and scope of precision strike and IiW as it now envisioned. Desert Storm provided the stimulus of combat that accelerated implementation; had it not occurred another ten years could probably have been added to these RMAs achieving the position they had by 2010.

Considering that both RMAs were widely accepted by year 2000 --- then perhaps five to ten years could have been taken off the timeline. The following are hypotheses about the key factors that affected the speed of these RMAs ---- and, had these factors been approached differently, could have increased the speed of adoption.

- These RMAs have not centered on a select set of platforms as have RMAs of the interwar period. Instead they have largely involved the integration ---- technically and operationally ---- of existing platforms and military units (in addition to some new systems, platforms and organizations). This has made it more difficult to develop concepts and doctrine because doctrine has historically been the province of each military service, and only in the past several decades does joint doctrine appear to have received more emphasis. It appears, however, that military service doctrine and practices dominated in the 1980s-1990s.

- Because these RMAs sweep across military services and civilian defense agencies, an essential challenge is coordination --- not the formation of new organizations. Coordination is a process. DoD has been on the one hand excessively focused on process, and on the other hand unable to make those processes adapt to needs for speed (e.g., in weapons acquisition or joint operational environments).

- Technology is a major factor in these RMAs. The scale and complexity of systems and their connections have required decades, simply in the technological complexities of their development, implementation into systems, and production for the force structure. The evolution of the technologies into military systems in the hands of units could have progressed more rapidly had the underlying disciplines in engineering ----- the development of design practices for "systems of systems" engineering ---- been accelerated through prototyping, experimentation and rigorous use of lessons learned from installing systems.

- The government's acquisition and management of systems ---- and the performance of companies in delivering those systems ---- added years to the implementation of these RMAs. Their actions not only delayed the RMAs. They created generational lags behind the technologies' progress in commercial applications and (in their cost overruns) diverted funding away from other projects that would have added to the progress of the RMAs.

- There have been few vigorous and intensely focused leaders for these two RMAs, and the few who have been identified have not provided for continuity of their effort upon their departure. Certainly leaders in both military and civilian organizations have been supporters, but none have provided enduring, enthusiastic support or the willingness to engage at all levels of change from concepts and testing, through to career management, organizational change and systems implementations. The absence of consistent and detailed leadership has been particularly influential on speed because the military has been extremely busy in conflicts and crises and the DoD is a much larger organization than in the interwar period. The absence of civilian leadership has been a factor because civilian control has been more pervasive than in the interwar period.

- In precision strike, two key organizations ---- TAC and SAC --- had mission and institutional obstacles to adoptions. SAC was focused on nuclear attack; it could have embraced large scale conventional precision strike earlier and set in motion the development of weapons to implement that. TAC ---- having employed LGBs in the late 1960s ---- delayed broader use because of preferences for dive bombing. Had it adopted LGBs more broadly it too could have accelerated the use of precision strike.

- In IiW --- overall and in subsets (e.g., IW, EW, etc) --- delays have been imposed by separations in organizational roles, practices, goals and perspectives in areas such as intelligence, communications, and command and control.

If the DoD is interested in RMAs as a concepts important to strategy, there are certain topics which it could consider for further research:

- A research program similar to that conducted in the 1990s on the interwar period, but focused on building an understanding of the RMAs in the Cold War and post-Cold War period.

- Examining the interwar RMAs in areas that appear to have received limited attention ---- the impact of process change as opposed to structural changes in organizations; government vs. private sector development and production; the role of acquisition practices; and, the development of manufacturing technologies and capacity.

- Examining strategies for peacetime competition in RMAs in the post-Cold War period when multiple nations have capabilities and understandings of the value of RMAs, and may chose to implement versions attuned to their particular situations.

- Studying the time required to develop the engineering intellectual and industrial base from which RMAs can progress, how that time factor has been changing, and how it may change in the future.

- Evaluating whether RMAs need to be addressed in a different manner because the U.S. faces so many diverse military competitions --- e.g., whether RMAs should be examined at their underpinnings as in IiW or as specific manifestations as in precision strike.

- The use of games ----- e.g., to what extent they can substitute for actual use of systems (particularly in network based RMAs), and to what extent they should be used to examine how to implement an RMA (as opposed to examining how an RMA capability could be employed).

In thinking about the future of these two RMAs there are several issues for concern that may add new obstacles to speed:

- In Precision Strike, its rate of progress may be affected in the future by two factors --- new means of destruction (e.g., from kinetic to laser, HPM, acoustic, cyber, etc.), and new classes of very difficult targets (e.g., deep underground facilities, specific subsystems of a satellite, nuclear plants without spreading radioactivity, etc.) DoD may try to address these opportunities and challenges through the same organizational and process mechanism that it used to implement precision strike up to this time. However, this future version of the RMA may be so different as to be inappropriate for the old method of absorption.

- While IiW appears to have been succeeding in traditional functional and operational roles (e.g., EW, IW, ISR, logistics), it is already being criticized for lack of progress in new areas such as cyberwarfare. Additionally the huge growth in IiW systems does not seem to have been accompanied by analysis in the value of additional information. A risk exists that the DoD will overinvest in the current version of IiW because it does not understand the limits, and underinvest in the next generational advances.

Overall, the concept of RMAs appears to have slipped in visibility and importance since about 1995. That may indicate that it has lost merit, or that it has lacked the continuity of support for it as a concept.

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