Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/1001--06-8951

The U.S. Naval Research Laboratory

Fulfilling the Roosevelts' Vision for American Naval Power

(1923-2005)

Authored By

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June 30, 2006

Front Cover

The Roosevelts Gold Medal for Science was conceived by the New York Council, Navy League of the United States, and designed by Tiffany, in 1986. It is awarded "to an individual, institution, or corporation for extraordinary scientific contributions to the security of America."

The Gold Medal carries the profiles of Franklin and Theodore Roosevelt, both assistant Secretaries of the Navy on their way to the White House, and both keen supporters of science and naval power. For over 100 years, the traditional objective of the Navy and the Navy League has been "Peace Through Strength — Strength Through Science."

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
30-06-2006

2. REPORT TYPE
Memorandum Report

3. DATES COVERED *(From - To)*
1923 - 2005

4. TITLE AND SUBTITLE

The U.S. Naval Research Laboratory (1923-2005)
Fulfilling the Roosevelts' Vision for American Naval Power

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Don DeYoung (NRL 1001.1), Jill Dahlburg (NRL 1001.2) Richard Bevilacqua (NRL 7200), Gerald Borsuk (NRL 6800), Jay Boris (NRL 6400), Simon Chang (NRL/MRY 7500), Richard Colton (NRL 1100), Robert Eisenhauer (NRL 8100), Herbert Eppert (NRL/SSC 7400), Edward Franchi (NRL 7100), Thomas Giallorenzi (NRL 5600), Donald Gubser (NRL 6300), Herbert Gursky (NRL 7600), Erik Mokole (NRL 5300), Francis Klemm (NRL 5700), John McLean (NRL 5500), James Murday (NRL 6100), Sidney Ossakow (NRL 6700), Ruth Preller (NRL/SSC 7300), John Schaub (NRL 8200), and Joel Schnur (NRL 6900)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
4555 Overlook Avenue, SW
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/1001--06-8951

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
One Liberty Center
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR / MONITOR'S ACRONYM(S)

ONR

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Since its establishment on July 2, 1923, the Naval Research Laboratory (NRL) has excelled in its mission of conducting a broadly based multidisciplinary program of scientific research and advanced technological development directed toward maritime applications of new and improved materials, techniques, equipment, systems, and ocean, atmospheric, and space sciences and related technologies. Products of the Laboratory include a number of innovations that have revolutionized capabilities of the United States Navy and of our Nation as a whole. Among these innovations are radar, which ushered in the era of modern warfare; inventing the first U.S. intelligence satellite; and conceiving several key ideas for satellite time-based navigational systems, which eventually led to the Global Positioning System (GPS). More recently, NRL has developed powerful new warfighting capabilities for a post-Cold War environment marked by regional conflict and terrorism. One example is Specific Emitter Identification technology that identifies any radar by its unique characteristics with such accuracy as to "fingerprint" it. It was selected by the National Security Agency as the national standard. Another is Dragon Eye™ an affordable, expendable, hand-launched 5.5-pound miniature surveillance plane with the radar signature of a bird. Carried by backpack, this airborne sensor platform provides U.S. Marine units deployed to Iraq with reconnaissance, battle damage assessment, and threat detection capabilities. A final example is Project Silent Guardian, implemented when there were concerns for military and civilian health during special events held in the Washington, DC, area during the 2005 Presidential Inauguration. This project marked the first demonstration of a capability for rapidly obtaining data for a broad range of pathogens in clinical specimens collected from the general population.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Don DeYoung
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UL	73	**19b. TELEPHONE NUMBER** *(include area code)*
Unclassified	Unclassified	Unclassified			(202) 767-2445

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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PREFACE

In 2005, the U.S. Naval Research Laboratory (NRL) was selected to receive the Roosevelts Gold Medal for Science by the New York Council, Navy League of the United States. Designed by Tiffany in 1986, the Medal is awarded "*to an individual, institution, or corporation for extraordinary scientific contributions to the security of America*."

The Roosevelts Gold Medal for Science was created in honor of Theodore Roosevelt and Franklin Delano Roosevelt. During their service to our nation as assistant secretaries of the Navy, and then as U.S. presidents, both were keen advocates of American naval power and strongly supportive of the vital role played by science in creating and sustaining it.

With minor modifications, the pages that follow contain the full nomination package provided to the New York Council of the Navy League for consideration by its award selection panel.

Don J. DeYoung
Executive Assistant to the Director of Research
U.S. Naval Research Laboratory

11 November 2005

INTRODUCTION

Origins: *Thomas Edison, Franklin D. Roosevelt, and Theodore Roosevelt, Jr.*

History reveals a strong relationship between technology and national security. Early in the last century, Thomas Edison's belief in that linkage led to his idea for establishing what would become the U.S. Naval Research Laboratory (NRL). In May 1915, when asked by a *New York Times* correspondent to comment on the war raging in Europe, Edison argued that the nation should look to science. "The Government," he proposed, "should maintain a great research laboratory." Secretary of the Navy Josephus Daniels seized the opportunity to enlist the great inventor's support. Edison agreed to serve as the head of a new body of civilian experts — the Naval Consulting Board — to advise the Navy on science and technology and to oversee the creation of the new laboratory. Working closely with the board was Franklin D. Roosevelt, the Assistant Secretary of the Navy.

On July 2, 1923, NRL was officially established. A marriage of technological innovation with national security interests was perhaps preordained given that Edison, America's most famous inventor, and Roosevelt, destined to be the nation's Commander in Chief, played roles in the Laboratory's origin. It was further fitting that Theodore Roosevelt, Jr., son of President Theodore Roosevelt, assumed his father's and cousin's former post as Assistant Secretary of the Navy and formally inaugurated NRL's opening as the principal speaker. His remarks were not recorded, but earlier Theodore Roosevelt, Jr. had told the House Subcommittee on Appropriations,

> "I feel strongly that the Navy must not be allowed to petrify. We will petrify unless we are constantly reaching out for new and better things. The research laboratory is in direct line with this thought."[1]

His view of the Laboratory was important because Roosevelt was formally in charge of the new facility. As the Naval Consulting Board had wished, NRL was placed administratively in the Secretary's Office, under the Assistant Secretary. This was done to ensure the Laboratory's focus on the long-term needs of the Navy rather than on short-term operational activities.

The Early Years through World War II: *Radio, Sonar, the First U.S. Radar, and more…*

NRL's three earliest divisions — Radio, Sound, and Metallurgy — pioneered the fields of radar, high-frequency radio, underwater sound propagation, and defect analysis in castings during the 1920s and 1930s. The Laboratory's work in those pre-war years proved vital to preparing the American Fleet for the approaching global war against fascism. A number of new devices, systems, and processes were developed, including: gamma-ray radiography for improving the production of high-quality steel for armor, ship frames, and fittings; the foundation for modern High-Frequency (HF) wave-propagation theory, which led to the Navy's acceptance of HF frequencies in naval communications; the first operational U.S. sonar to detect and track enemy submarines; and the first U.S. radio recognition Identification Friend-or-Foe system capable of identifying friendly aircraft returning to carriers under poor visibility. But most noteworthy was the Laboratory's invention of modern radar in the early 1930s.

NRL installed the first operational radar on the battleship USS *New York* in 1939. The technology was transferred rapidly to industry and units were fielded in time for duty in the great Pacific naval battles of World War II, contributing to crucial victories at Coral Sea, Midway, and Guadalcanal. This work also laid much of the basis for the rapid development of radar during the war. Among these included NRL's

[1] U.S. Congress, 67:4, House, *Hearings Before the Subcommittee of the House Committee on Appropriations in Charge of the Navy Department Appropriation for 1923* (Washington: GPO, 1922), p. 728.

Manuscript approved March 15, 2006.

invention of monopulse radar, a breakthrough in precision target tracking, and the first U.S. airborne radar, used extensively by the U.S. Navy and Army Air Corps and the British military.

Work in other areas also continued during the war, with more than 900 applied research projects conducted. One of the developments was a new uranium separation process called liquid thermal diffusion, which was a significant contribution to the success of the Manhattan Project. In a related area, NRL was the first to conceive, propose, and investigate the use of nuclear power in submarine propulsion, and during the Cold War it contributed to the development of the world's first atomic-powered submarine, the USS *Nautilus*.

Cold War: *The First Intelligence Satellite, the Global Positioning System, and more…*

Following the end of World War II, NRL focused on basic research into the Navy's operational environments — from the ocean depths, on the sea surface, and into sky and space.

Deep sea search technologies were developed by NRL and were used by expeditions to find the U.S. Navy's lost submarines, USS *Thresher* and USS *Scorpion*, and the lost French submarine *Eurydice*, and to locate and recover a lost H-bomb off the coast of Spain. The Laboratory's emergency search mission was later transferred to other Navy organizations.

For the realm of the ocean surface, NRL developed Aqueous Film-Forming Foam in the aftermath of the destructive fires aboard the USS *Forrestal* and USS *Enterprise.* This firefighting agent is used by U.S. aircraft carriers, all branches of the U.S. armed forces, and NATO members, as well as fire departments throughout the world.

For the skies, NRL developed synthetic lubricants needed for the new gas-turbine engines of the high-performance jet aircraft that dominated the skies in the Korean War. Essentially all turbine engines now used by military and civilian aircraft are lubricated with ester oils whose development was based on this early work at NRL.

For the final frontier, the birth of the U.S. Navy space program was marked by NRL's use of captured German V-2 rockets to monitor the Sun's behavior and its effect on naval communications. The Laboratory also conducted America's first satellite program by directing the Vanguard project and by developing the world's first satellite tracking system, which later formed the basis of NRL's development of the Navy Space Surveillance System. Not long thereafter, the Laboratory invented the world's first intelligence satellite (GRAB-I), launching it only 52 days after an American U-2 was lost over Soviet territory. The GRAB-I spacecraft made a profound impact on the Nation's intelligence gathering capabilities and on national security decision-making, particularly with regards to the deterrence of nuclear war.

Finally, NRL formulated the original concepts and developed the satellite prototypes for the NAVSTAR Global Positioning System, which earned NRL the coveted Collier Trophy "for the most significant development for safe and efficient navigation and surveillance of air and spacecraft since the introduction of radio navigation 50 years ago." The military and commercial applications of GPS are revolutionary and pervasive.

Regional Conflict and Terrorism: *Dragon Eye, InfraLynx, Silent Guardian, and more…*

Regional Conflict: Today, NRL's multidisciplinary R&D program continues to be conducted with an awareness that the challenges posed by international conflict can, in part, be addressed by innovative R&D solutions. Technologies developed by the Laboratory have addressed traditional military challenges in post-Cold War regional conflicts such as in Kosovo and Iraq, as well as for continuing security requirements like national missile defense. The following are three examples.

> NRL's AN/ALE-50 electronic warfare decoy protects combat aircraft so well that it has earned the nickname "Little Buddy" from our pilots. In the Kosovo campaign alone, 1,479 of these decoys were used and the system was credited with saving several aircraft.
>
> NRL's Dragon Eye™ is an affordable, expendable, hand-launched, 5.5-pound miniature surveillance plane with the radar signature of a bird. Carried by U.S. Marines in a backpack, this airborne sensor platform provides small unit reconnaissance, battle damage assessment, and threat detection capabilities. It has been deployed with the 1st Marine Expeditionary Force in support of Operation Iraqi Freedom, and was mentioned in a *New York Times* front-page article about the U.S. Marines' fight for Falluja.[2]
>
> NRL was given responsibility for mission design, spacecraft engineering, and flight operations for a space mission to test advanced sensor and component technologies for missile defense systems. NRL put the satellite *Clementine* into lunar orbit, returning America to the Moon for the first time since 1972. Built in less than 1/2 the time and for 1/5 the cost of similar space probes, Clementine was so simple to operate that its mission control center comprised eight engineers working in a warehouse in Alexandria, Virginia.

Terrorism: In addition to regional conflicts that feature traditional military threats, America is engaged in a prolonged struggle with an opportunistic, fanatical enemy who has unlimited apocalyptic goals and is not deterred by traditional means. Technologies such as sensors, communications, and intelligence systems have become even more vital. NRL is providing improved capabilities in such areas for homeland defense and the war on terrorism. The following are three examples.

> NRL's Specific Emitter Identification technology identifies any radar by its unique characteristics with such accuracy as to "fingerprint" it. In fact, it can distinguish between identical models produced off the same assembly line. The National Security Agency selected it as the national standard. It was used in Kosovo, but its uses go beyond that of traditional military requirements. Coast Guard vessels, naval warships, and aircraft use it to monitor the movement of materials used in weapons of mass destruction.
>
> Three days after the September 11 terror attacks, NRL designed an interoperable communication infrastructure that provides assured communication capabilities to military and civilian authorities. The Infrastructure Linkage and Augmentation System (InfraLynx) allows First Responders to communicate when local infrastructure is destroyed. It was deployed by the Office of Domestic Preparedness during the 2002 Winter Olympics in Salt Lake City and Super Bowl XXXVII. InfraLynx has also supported counter-terrorism training and WMD preparedness drills.
>
> Project Silent Guardian was implemented when there were concerns for military and civilian health during special events held in the Washington, D.C., area during the 2005 Presidential Inauguration. A team composed of NRL scientists, Navy reservists, and Air Force staff successfully made the first demonstration of a capability for rapidly (i.e., in less than 24 hours) obtaining data for a broad range of pathogens in clinical specimens collected from the general population. The team accurately detected samples spiked with inactivated bio-threat agents in blind trials and identified numerous cases of influenza in patient samples collected from military treatment facilities.

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[2] Dexter Filkins, "In Falluja, Young Marines Saw the Savagery of an Urban War," *New York Times*, 21 November 2004, p. 1.

Conclusion

At its most fundamental, the idea behind NRL's creation was to help build American sea power and protect national security through technological innovation. The record shows that NRL has helped make the U.S. Fleet the most formidable naval fighting force in the world. And, over the more than eight decades since its establishment, the Navy's corporate laboratory has fulfilled Thomas Edison's vision with a record of technical excellence that has had a profound impact on national security.

The unclassified innovations described in this report are only representative of the thousands, many of them classified, that NRL has produced since 1923. It should also be noted that the more recent achievements described in the last section on "Regional Conflict and Terrorism" may not have yet reached full fruition in terms of applications and impact. Some research can take as much as 20 years or more to reach that point.

This representative selection of achievements confirms that NRL has made a profound difference, in times of war and in times of peace, through the creative work of scientists and engineers who serve in the nation's interest. Knowing the Laboratory's record of excellence, the following notable political, military, and technical experts made these comments in 1998 when NRL celebrated its 75th anniversary.

> "What you do here [at NRL] is probably the biggest force-multiplier that we have in our military."
>
> — Senator John Warner (Chairman, Senate Armed Services Committee)

> "NRL has a reputation for clever solutions where others thought none were possible. NRL continues to be a national treasure."
>
> — VADM Arthur K. Cebrowski (USN, Ret.) (former Director, Force Transformation)

> "I know from experience that there are few other institutions—public or private—which have had a greater impact on American life in the 20th century, both in terms of military needs and civilian uses."
>
> — Norman Augustine (CEO of Lockheed Martin)

> "This efficient, relatively small government agency has had an enormous impact, touching the lives of just about every American…the Naval Research Laboratory is a national asset, not just a military asset."
>
> — Peter Teets (former Director, National Reconnaissance Office)

> "NRL is the equivalent of the most significant technology jewel in our country."
>
> — Robert Galvin (Chair of the Executive Committee of Motorola, Inc.)

> "NRL is important to all of us — to defense industry and to science."
>
> — Dr. Charles Townes (Nobel Laureate, inventor of the laser)

In summary, NRL's impressive success in transferring technology to industry, academia, and other government agencies, and the national impact made by those technological innovations, prove the value of having a great research laboratory, maintained by the Government, in service to the U.S. Navy.

THE EARLY YEARS THROUGH WORLD WAR II

Gamma-Ray Radiography

Achievement

NRL's development of gamma-ray radiography was an important contribution to the nondestructive testing (NDT) of metal castings and welds. The method, devised by R.F. Mehl in the 1920s, entailed the use of gamma-ray radiation as a shadow-graphic technique to detect flaws in cast or welded steels.

This technique was first used to ascertain the extent of suspected flaws in the sternpost castings of the U.S. Navy's new 10,000-ton heavy cruisers.[3] The integrity of these post castings was vital to the successful operation of the vessels. Upon examination, the sternpost castings of these vessels were found to be faulty, and all 10 cruisers of the affected class subsequently had to be repaired to avoid operational failure.

During the five-year period before World War II, this NDT technique facilitated the development of improved steel casting processes. By trial and nondestructive examination, the methods used in all stages of the molding, casting, and testing of steel were improved.

Impact

Mehl's work on the Navy's cruiser sternpost castings established gamma-ray radiography as an NDT technique in this country.[4] It also contributed to American seapower by improving the production of high-quality steel for armor, ship frames, and fittings.

In 1941, the American Society for Nondestructive Testing originated the biannual Mehl Honor Lecture series to honor R.F. Mehl for his pioneering work in gamma-ray radiography. The selected speaker is chosen for having made an outstanding contribution to the field of NDT.[5]

Primary Reference Documents

- Mehl, R.F., Doan, G.E., and Barrett, C.S., "Radiography by the Use of Gamma Rays," *Transactions of the American Society for Steel Treating*, Chicago, 1930.

- Barrett, C.S., Gezelius, R.A., and Mehl, R.F., "The Technique of Radiography by Gamma Rays," *Metals and Alloys*, December 1930.

- Mehl, R.F., "Report on Use of Gamma Rays for Radiographic Inspection of Sternpost and Keel Knuckle Casting," NRL Report, June 30, 1931.

- Mehl, R.F., "Radiography Inspection with Gamma Rays," *American Machinist*, Vol. 75, 278-80 (1931).

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[3] Taylor, A.H., *The First Twenty-Five Years of the Naval Research Laboratory* (NAVEXOS P-549), April 1948, p. 26.

[4] *Materials Science and Technology Division History*, NRL/PU/6300--93-240 (May 1993), p. 91.

[5] Lambert, R.H., VADM, "A Tribute to Robert F. Mehl," *Materials Evaluation*, March 1972, p. 15.

Development of High-Frequency Radio Equipment

Achievement

In addition to NRL's pioneering work in radio propagation, the Laboratory's development of radio equipment, such as quartz-crystal frequency control, high-power transmitters, and receivers, led to the adoption and extensive utilization of high-frequency (HF) communications by the Navy. Many of these NRL developments were adopted Navy-wide. For example, the quartz crystal oscillator circuit became the Navy standard oscillator circuit (1924),[6] and the Model RG receiver was the first to reach the Fleet in large numbers, becoming the Navy's principal receiver (1925) for over a decade and continuing in service during World War II.[7] NRL's HF radio equipment enabled the following achievements that, in turn, facilitated Navy-wide adoption of HF communications.

- An important factor in the Navy's adoption of HF was the performance of the NRL-developed HF transmitter and receiver carried by USS *Shenandoah*, the Navy's dirigible, during its transcontinental trip in 1924. This equipment accomplished the unusual feat of remaining in communication with NRL throughout the entire trip.[8]

- An NRL HF crystal-controlled transmitter communicated directly with the flagship USS *Seattle* during the cruise of the Fleet to Australia in 1925, a demonstration that contributed importantly to the Navy's adoption of HF.

- NRL maintained regular communications with the Antarctic base and support ships of Commander R.E. Byrd's expedition to the South Pole in 1929. The base and ships were equipped with NRL-designed and -fabricated radio gear.[9]

Impact

NRL's advances in radio equipment made possible the Navy's adoption of that part of the radio-frequency spectrum known as the HF band (2 to 30 MHz). That technological advance had a profound effect on naval communications for the next 50 to 60 years during times of peace and war.

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- Crossley, A., "Piezo-Electric Crystal-Controlled Transmitters," *Institute of Radio Engineers*, January 1927.

- Model RG Receiver, *Naval Radio and Sound Reports*, Project V-6E-26 (1925) and Project V-6E-27 (1927 and 1933).

- "Report of the Shenandoah Flight," *Naval Radio and Sound Reports*, December 1924.

[6] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 51.

[7] *Ibid*., p. 60.

[8] *Ibid*., p. 46.

[9] Taylor, A.H., *Radio Reminiscences: A Half Century* (NRL, Washington, DC, 1948), pp. 134-135.

Radio Propagation and the "Skip-Distance" Effect

Achievement

In 1925, NRL discovered the principles governing the "skip-distance" effect, which could not at the time be explained by the prevailing wave-propagation theory. The effect refers to radio signals that disappear after the "ground wave" dissipates but reappear at a considerable distance, varying with frequency, time of day, and season. Building upon the work of Sir Joseph Larmor, NRL's A. Hoyt Taylor and E.O. Hulburt jointly published in 1926 a modification of the theory that adequately explained the high-frequency "skip-distance" effect and that agreed with the experimental data.[10] In connection with this high-frequency-propagation work, NRL was the first to determine the frequency above which radio waves would penetrate the Earth's atmosphere and propagate through outer space, making radio communication in space possible.[11] NRL would later develop the world's first satellite communication system using the Moon as a relay.

NRL's work in this area further demonstrated that around-the-world HF transmissions could be obtained through successive reflections from the Earth's ionosphere with the proper choice of frequency, time of day, and season. Encirclement of the globe as many as three times in the same transmission and in both directions was observed in 1926. At the same time, reflections of the pulsed HF transmissions from Earth surface prominences, currently called "backscatter," were first observed. These HF "backscatter" observations generated the first concept of detecting and ranging on targets over very long distances.[12] This concept led to the later development of over-the-horizon radar by NRL.

Impact

NRL's seminal work in the field of radio propagation laid the foundation for modern HF wave-propagation theory, led to the Navy's acceptance of HF radio frequencies which had a profound effect upon naval communications for the next 50 to 60 years, led to NRL's development of the world's first satellite communication system, and led to the Laboratory's development of over-the-horizon radar.

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- Taylor, A.H. and Hulburt, E.O., "Wave Propagation Phenomena at High Frequencies," *Naval Radio and Sound Reports*, September 1925.
- Taylor, A.H., "An Investigation of Transmission on the Higher Radio Frequencies," *Institute of Radio Engineers*, December 1925.
- Taylor, A.H. and Hulburt, E.O., "The Propagation of Radio Waves Over the Earth," *Physical Review*, Vol. 27, February 1926.

[10] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, pp. 43-45.

[11] *Ibid*., p. 115.

[12] *Ibid*., p. 44.

Invention of U.S. Radar

Achievement

Prior to the development of radar, Navy ships could track other ships or aircraft only by using optical techniques, sound ranging, or primitive radio direction finding. New methods of detection and ranging were necessary. In 1922,[13] while working on radio direction finders for aircraft, A.H. Taylor and L.C. Young noted a distortion of "phase shift" in radio signals reflected from a steamer on the Potomac River. In short, NRL had detected a moving ship by radio waves and had, as a result, discovered the radar principle.[14] Eight years after the initial discovery of the radar principle, NRL scientists observed that reflections of radio waves from an airplane could also be detected.

From 1930 to 1940, NRL explored the use of radio for detection and ranging. In 1933, the use of a pulse technique to detect aircraft and ships was proposed by Young. R.M. Page made major advances over the next few years in the area of transmitters and receivers, eventually developing the highly important "duplexer" in 1936. The duplexer permitted the use of the same antenna for both transmitting and receiving. The pulse technique combined with the duplexer did away with the separate receiving and transmitting antennas that most of the other early radar developers employed. Page and Young received the patents for the duplexer, an invention that dramatically changed the nature of radar in the U.S. and abroad.

Impact

NRL invented, developed, and installed the first operational U.S. radar, the XAF, on the battleship USS *New York* in 1939. It was rapidly transferred to industry for production. By the time of the attack on Pearl Harbor, 20 radar units were in operation. Radar of this type contributed to the victories of the Coral Sea, Midway, and Guadalcanal.[15]

The invention of radar and the developments that flowed from it (e.g., monopulse radar and over-the-horizon radar) are among the foundations of modern military power. And, as a sensor for navigation and surveillance, radar plays a major role in the operation of civilian transportation systems, weather forecasting, astronomy, and automation, among other uses.

Primary Reference Documents

- U.S. Patents: No. 1,981,884 to Taylor, A.H., Hyland, L., Young L.C., "System for Detecting Objects by Radio," 1934; No. 2,512,673 to Page, R.M., "Radio Pulse Duplexing System," 1950; No. 2,688,746 to Page, R.M. and Young, L.C., "Impedance Control Coupling and Decoupling Systems," 1954.

- R.M. Page, Laboratory Notebook 171, Vol. III, March 1934; letter from NRL to the Bureau of Engineering, June 11, 1936, in File S-S67-5 #1, National Archives Building.

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[13] The discovery was made by researchers working for NRL's predecessor organization, the Naval Aircraft Radio Laboratory (NARL). When the facilities of the new Laboratory became available, the personnel and activities of NARL were transferred to become the major component of NRL's Radio Division.

[14] For this work, Taylor has been called the "Father of Radar." [Howeth, L.S., 1963, *History of Communications-Electronics in the United States Navy*, Washington (Chapter XXXVIII, Sec 4) Library of Congress Catalogue Number: 64-62870; http://earlyradiohistory.us/1963hw.htm]

[15] King, E.J., ADM, *U. S. Navy at War: 1941-1945* (Navy Department, Washington, DC, 1946), p. 226.

First Operational U.S. Sonar

Achievement

Underwater acoustic research was started by the U.S. Navy in 1917 with a small group at the U.S. Naval Experimental Station in New London, Connecticut, investigating the use of underwater sound in World War I. This group, headed by H.C. Hayes, was eventually moved to NRL on its opening in 1923.

Hayes and his colleagues decided that the passive sonic devices used in World War I were seriously limited in the detection of enemy submarines. It was their belief that active echo-ranging sonar would provide the best antisubmarine warfare system for surface ships. This approach was taken from the start of the new Sound Division at NRL, where practically all of the U.S. Navy's R&D in sonar prior to World War II was carried out.[16]

NRL's first effort was to develop an improved quartz-steel transducer. Extensive effort was placed on each of the components of the new sonar system, from the transducers and signal processing to the mechanical mounting and housing functions. Of particular significance was the development of the streamlined sonar dome to house the transducer. The dome enabled surface ships to make attacks at speeds up to 15 knots. In 1927, a number of U.S. naval vessels conducted tests with the NRL quartz-steel echo-ranging sonar. This was the first practical sonar based on the 1918 demonstration by P. Langevin, a French physicist, of the possibility of echo-ranging or "pinging" at supersonic frequencies.[17]

A later system, the Echo Detection Equipment Model QB, became the first operating sonar used by the U.S. Navy.[18]

Impact

Sonar transformed naval warfare by improving the ability of surface ships and submarines to detect and track enemy submarines.

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- U.S. Patent No. 2,005,741 to Hayes, H., "Magnetostrictive Sound Generator," June 25, 1935.
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[16] "Sonar Systems," NRL Achievements File (1982). This source cites as references: Sonar Detector, OPNAV P413-104, Navy Department, Chief of Naval Operations, Washington, DC, 1946; and "Notes on Underwater Sound Research and Applications Before 1939," by E. Klein, ONR Report ACR-135, September 1967.

[17] Baxter, III, J.P., *Scientists Against Time* (Little, Brown & Co., Boston, 1946), p. 171. This book is the brief official wartime history of the Office of Scientific Research and Development.

[18] Stephenson, E.B., "Instructions for Echo Detection Equipment Model XQB," NRL Report RA55A227, August 1934.

Liquid Thermal Diffusion Process

Achievement

NRL was the first research center that GEN Leslie Groves visited when he took charge of the Manhattan Project in September 1942. The Laboratory at that time had the distinction of being the first U.S. government agency to support uranium research in 1939.[19] One result of that support was the first successful separation of uranium isotopes by the liquid thermal diffusion process.

The liquid thermal diffusion process was one of the three methods that the Manhattan Project used to obtain the enriched uranium necessary to form the first atomic bombs. In its early stages, the project employed two enrichment methods, but in 1944 the project hit a technical impasse. When the project's technical director, Dr. Robert Oppenheimer, became aware of NRL's research in using liquid thermal diffusion as a method of separating uranium isotopes, he ensured its use in the Manhattan Project.[20] In June 1944, the blueprints of NRL's liquid thermal diffusion plant were sent to Oak Ridge, Tennessee, and within three months, the first columns of the Oak Ridge uranium separation plant were in operation. In the spring of 1945, Oak Ridge was producing uranium-235 for the Hiroshima weapon.[21]

The Laboratory's contribution was accomplished by a team led by P. Abelson at NRL's main site and later at a larger pilot plant built at the Philadelphia Naval Shipyard in 1943.[22] Abelson had invented the process earlier with NRL funding while he was employed by the Carnegie Institution of Washington. But, by 1941 he had become an NRL employee hired to investigate the scale-up of the process. Abelson also invented the first practical method for making uranium hexafluoride, a key material needed for the process of U-235 separation.[23]

Impact

The liquid thermal diffusion process was a significant contribution to the success of the Manhattan Project.

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[20] Rhodes, R., *The Making of the Atomic Bomb* (Simon & Schuster, Inc., New York, 1988), pp. 551-553.

[21] Hewlett and Duncan, p. 21.

[22] Smyth, H.D. "Atomic Energy for Military Purposes," cited in R.E. Ruskin, "Separation of Isotopes," NRL Progress Report, September 1947.

[23] Rhodes, p. 550.

Aircraft Radio Homing System

Achievement

When the first aircraft carriers — the USS *Langley* (CV-1) in 1922, and the USS *Lexington* (CV-2) and USS *Saratoga* (CV-3) in 1928 — became available, there was need for a suitable means of navigating carrier-based planes to and from carriers and air facilities ashore.[24]

To solve this problem, NRL developed an aircraft radio homing system that was installed on all Navy aircraft carriers and their aircraft and that provided the primary means for aircraft to navigate back to their carriers during World War II. NRL's experimental model was installed on the carrier USS *Saratoga*, the flagship of the Commander, Aircraft Battle Force, then ADM E.J. King in May 1938.

After witnessing its performance, ADM King, in a letter to the Navy Department dated August 29, 1938, recommended, "Adopt the (Model YE) system for primary means of homing radio aircraft." As a result, the system was installed on all aircraft carriers and was used extensively in the Pacific during World War II.[25]

The homing system used two frequencies that confused the Japanese admirals, who realized that U.S. aircraft were successful in returning to their carriers but did not understand how this was accomplished. In one reported incident during a battle in the Marianas, in the waning hours of daylight, when American planes followed the stricken enemy nearly to the limit their fuel would permit, most of the planes and their pilots were saved by homing back to their carriers in the dark with this equipment.[26]

Impact

This system had a major impact on Pacific combat operations during World War II. The many glowing reports received from combat units and individual pilots whose lives were saved under trying circumstances attested to the importance and value of this NRL development. The British also eventually adopted this system for their carrier aircraft. The system continued in use until it was replaced by the Tacan system in 1960.[27]

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[24] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 271.

[25] *Ibid*, p. 273.

[26] *Ibid*, p. 274; Taylor, A.H., *Radio Reminiscences: A Half Century* (Naval Research Laboratory, Washington, DC, 1948), p. 171.

[27] Gebhard, p. 274.

First Proposal of a Nuclear Submarine

Achievement

The use of nuclear power to propel submarines under water was first proposed by an NRL physicist, R. Gunn, soon after fission was discovered in 1939.[28] In March 1939, Navy officials, one of which was Gunn, met with several civilian scientists who felt the military should be made aware of the vast possibilities of nuclear fission. Among the civilian scientists was Enrico Fermi. While most of the Navy personnel present at the meeting concentrated their attention on a nuclear weapon, Gunn was conceiving the idea of using nuclear power to drive the world's first nuclear submarine.[29]

Within a few days after this historic meeting, Gunn had requested and received $2,000 for preliminary work on the possibility of developing nuclear power for ship propulsion.[30] Later, in June 1939, in a memo to the NRL Director, Gunn stated:

> "Under certain special circumstances of bombardment by neutrons, the heavy element uranium dissociates into two other elements with the evolution of tremendous amounts of energy which may be converted directly into heat and used in a flash boiler steam plant. Such a source of energy does not depend on the oxidation of organic material and therefore does not require that oxygen be carried down in the submarine if uranium is used as a power source. This is a tremendous military advantage and would enormously increase the range and military effectiveness of a submarine."

In April 1946, NRL forwarded a report to the Bureau of Ships entitled "The Atomic Energy Submarine," which concluded that it was considered feasible to construct atomic power plants of a size and output suitable for ship propulsion. This report also marks the first interest in liquid metal coolants for reactors.[31]

Impact

NRL was first to conceive, propose, and investigate the use of nuclear power in submarine propulsion, and through subsequent efforts the Laboratory contributed to the planning and development of the world's first atomic-powered submarine, the USS *Nautilus*. The nuclear submarine is one of the most formidable weapons systems ever developed.

Primary Reference Documents

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[28] Pegram, G.B., to Hooper, Admiral S.C., March 16, 1939, quoted in Fermi, *Atoms in the Family*, p. 162-163; H.W. Graf, memorandum for file, March 17, 1939, *AEC.*

[29] Hewlett, R.G. and Duncan, F., *Nuclear Navy: 1946-1962* (University of Chicago Press, Chicago, 1974), p. 16.

[30] NRL Memorandum, "Early History of Uranium Power for Submarines," May 1, 1946.

[31] Address by Honorable James H. Wakelin, Jr., Assistant Secretary of the Navy for Research and Development, before the 22nd Annual Meeting of the American Power Conference in Chicago, Illinois, March 29, 1960, p. 9.

Identification Friend-or-Foe Systems

Achievement

In the 1930s, neither the Army nor the Navy had a device that could adequately identify targets on the ground, sea, or in the air, particularly in overcast weather and at night. Identifying friendly planes returning to carriers under poor visibility was an especially serious problem. To solve the problem, NRL sought a solution through the use of radio waves.

NRL developed the first U.S. radio recognition identification friend-or-foe (IFF) system, the Model XAE, in 1937. This system provided coded transmissions from aircraft, which were received for identification aboard ship, and transmitted back to aircraft for verification. In 1939, NRL devised the first U.S. IFF system in which radar pulses received by a target ship or aircraft were repeated back to the radar and displayed as a pulse associated with the echo pulse on the scope. As part of this system, NRL's R.M. Page developed the first U.S. pulse transponder, basic to pulse IFF systems, and pulse beacon systems.[32]

The Mark X IFF was a later radar beacon system developed by NRL. It was essential to the military because it reduced fratricide when using beyond-visual-range weapons. By 1958, the FAA had established the Air Traffic Control Radar Beacon System (ATCRBS), essentially the civil version of the Mark X. The International Civil Air Organization later adopted the ATCRBS, making the Mark X the basis of the world's air traffic control system.

In 1948, NRL began research seeking a high-security IFF system. NRL's work, as well as the work of institutions such as the Air Force Cambridge Laboratory, led to the Mark XII IFF system in 1960.[33] It was the first IFF system to use cryptographic techniques to prevent deception where an enemy appears as a friend by using a captured transponder (the device giving the "yes" answer to interrogations), which had been experienced in World War II.

Impact

The first U.S. IFF system, NRL's Model XAE, met an urgent operational requirement to allow discrimination of friendly units from enemy units. In subsequent developments, the Mark X impacted U.S. and allied armed forces, as well as national and world civil airways, and the cryptographic Mark XII essentially nullified the threat of deception by an enemy using captured IFF transponders.

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[33] *Ibid*., p. 259.

First American Airborne Radar

Achievement

Prior to the entry of the U.S. into World War II, and in anticipation of having to contend with the German submarine menace, NRL developed the first American airborne radar, the Model ASB, in 1941. During the war, it was known as the radar that fought the war from the air in the Pacific.[34]

It was the first operational U.S. airborne radar widely used for bombing, detection of ships and surfaced submarines, and airborne intercept. The Model ASB was the first radar to be used in carrier-based aircraft, employed in attacking and destroying Japanese ship convoys in the Pacific. It was also very effective against submarines because it tremendously widened the area that could be covered by patrol planes.[35]

Experience with this type of radar led to NRL's involvement in the UHF E2 Airborne Early Warning Radar, microwave intercept radar, and antisubmarine warfare periscope detection radars.

Impact

This radar saw extensive use during World War II, not just by the U.S. Navy and Army Air Corps, but also by the British military. It was installed almost universally in U.S. naval aircraft and became known as the "workhorse of Naval Aviation." Over 26,000 units were procured (from 1942 to 1944), the largest procurement of any model radar during the war.[36]

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[35] Taylor, A.H., *The First Twenty-Five Years of the Naval Research Laboratory* (NAVEXOS P-549), p. 215.

[36] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 201.

THE COLD WAR

Monopulse Radar

Achievement

To overcome the angular limitations of existing radars, NRL developed the first monopulse radar in 1943. The monopulse technique makes angular determinations simultaneously on each individual received pulse. This new type of radar provided a tenfold improvement in angular accuracy over previous fire and missile control radars at longer ranges.[37] The monopulse radar is now the basis for all modern tracking and missile control radars. Although monopulse radar was developed independently in other countries that often treated the work as classified, the Laboratory's R.M. Page holds the U.S. patent on this technique.

The monopulse technique was first applied to the Nike-Ajax missile system, which was the nation's U.S. continental air defense system. The radar of this system was patterned after NRL's experimental model. After additional improvements to provide a more compact and efficient monopulse antenna feed and lobe comparison waveguide circuitry, monopulse tracking radar became the generally accepted tracking radar system for military and civilian agencies, such as the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA). In fact, NRL's work eventually led to the AN/FPS16, developed jointly by NRL and RCA, which was the first radar designed especially for missile ranges. It was used to guide the launchings of the first U.S. space satellites, *Explorer I* and *Vanguard I*, at Cape Canaveral in 1958.[38]

Impact

The invention of monopulse (simultaneous lobing) tracking radar was a breakthrough in precision target tracking. Monopulse radar performance is critical to gunfire control, missile guidance, missile-range precision launch, range safety, space vehicle tracking, FAA civil aircraft landing systems, Navy aircraft carrier landing systems, and target recognition.

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[37] Gebhard, L.A., *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratory*, NRL Report 8300, 1979, p. 200.

[38] *Ibid*., p. 200.

First Far-Ultraviolet Spectrum of the Sun

Achievement

In 1946, using a captured German V-2 rocket, NRL scientists obtained the first far-ultraviolet spectrum of the Sun from beyond the atmospheric boundary. NRL was not alone in the early attempts to measure the solar ultraviolet spectrum as Johns Hopkins University's Applied Physics Laboratory obtained excellent results only 6 months after NRL.[39]

The successful flight of October 10, 1946, carried cosmic ray detectors, pressure and temperature gauges, radio transmitters, and antennae to measure propagation through the ionosphere, as well as a spectrograph.[40] Although earlier flights had returned scientific data revealing cosmic-ray counts and pressure and temperature information, the successful retrieval of an ultraviolet spectrum of the Sun captured the attention of both the scientific and popular press. The *Washington Post* heralded the discovery of the "new ultraviolet" and reproduced samples of two spectra on page 1. The *New York Times*, *Times Herald*, and *Washington Star* all followed suit.[41]

Impact

Scientifically, NRL had extended the known spectrum of the Sun, but more significantly, this achievement marked the birth of space-based astronomy and the U.S. Navy's space program.

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[41] DeVorkin, D.H., *Science with a Vengeance* (Springer-Verlag, New York, 1992), pp. 143-144.

First Detection of X Rays From the Sun

Achievement

With the launch of an experiment aboard a V-2 rocket on September 29, 1949, NRL directly confirmed that X rays from the Sun are a principal cause of ionization in the E region of the Earth's ionosphere.[42] Additional experiments, aboard a Viking rocket flight and two Aerobee firings, later indicated that the solar X-ray spectrum is adequate to account for all of E-layer ionization.[43] This pioneering research opened the field of solar X-ray astronomy that the Laboratory explored so extensively in the 1950s and thus contributed profoundly to the understanding of the physical processes in the solar atmosphere. A practical benefit of this research includes the improved understanding of the effects of solar disturbances on radio communication and an improved ability to predict the influence of solar particle emissions on the radiation environment of manned space flight.

NRL's H. Friedman led the Laboratory's pioneering efforts in X-ray astronomy. In 1969, he received the National Medal of Science, the U.S.'s highest honor for scientific achievement, for "pioneering work in rocket and satellite astronomy and in particular for his contributions to X-ray astronomy." More recently, in honor of this work he received the coveted Wolf Foundation Prize for Physics in 1987. The Wolf Prize committee recognized Friedman and the other two co-recipients of the award:

> "as the principal founders of X-ray astrophysics, a new field of astronomical science which has proven to be a prolific source of fundamental discoveries and deeper physical understanding about high-energy processes in the universe. Their work has profoundly influenced every area of astronomical research. All agencies engaged in space science are now developing major orbiting facilities for X-ray observations, which will play a vital role in the future of astronomical science."

Impact

Solar X-ray emission is used to predict the state of the ionosphere and its effect on radio frequency transmission, especially at the HF frequencies. This was of major importance to Naval communications. The knowledge gained from the first detection of X rays from the Sun was a major milestone in a continuing endeavor by NRL that began with E.O. Hulburt's theoretical efforts[44] in the late 1920s and continued through the SOLRAD satellite series, as well as other space satellite research programs.

Primary Reference Documents

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The Principles of Fracture Mechanics

Achievement

Fracture mechanics is a field that recognizes that all structures are manufactured with, or will ultimately contain, flaws that govern the eventual failure of the structure. The study of the stresses caused by the flaws, and the material's resistance to failure from them, forms the basis for the field of fracture mechanics. Fracture mechanics permitted, for the first time, the capability to calculate the strength of structures containing defects, which inevitably occur in fabrication or during service operation. The net result of these new design principles increased the reliability of structures due to improved design capability and an improved predictive capability of in-service damage.

NRL's G.R. Irwin is recognized as the pioneer of modern fracture mechanics.[45] He developed the scientific principles for understanding the relationships between applied stresses and cracks or other defects in metallic materials. Irwin developed, around 1947, the concept that fracture toughness should be measured in terms of resistance to crack propagation. Critical values of the stress intensity describing the onset of fracture, the commencement of environmental cracking, and the rate of fatigue crack growth were established later.

As a consequence of Irwin's scientific work, fracture mechanics is now taught in many graduate schools and remains an active field of R&D today.

Impact

Using these fracture-safe design principles, NRL assisted in the solution of many important military and commercial problems, for example, by solving the catastrophic failures in commercial jet aircraft in 1953, and the fracture problems experienced by the Polaris and Minuteman missile programs in 1957.[46] Fracture mechanics has been applied throughout the world for the design of any structures where sudden, catastrophic failure would cause loss of life or other serious consequences. Examples include nuclear reactor pressure vessels, submarines, aircraft and missiles, and tanks for storage of toxic or flammable materials.

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Molecular Structure Analysis and the Nobel Prize

Achievement

NRL has produced two Nobel Laureates, J. Karle and H. Hauptman, who each received the Nobel Prize for Chemistry in 1985 for devising direct methods employing X-ray diffraction analysis in the determination of crystal structures. The seminal research paper, "The Phases and Magnitudes of the Structure Factors," was published in 1950. The major events leading to these new methods were: quantitative molecular structure analysis in 1948; foundation mathematics for the X-ray phase problem in 1949; and the first general procedure for solving crystal structure problems in 1963.[47] As experience with applications developed, I. Karle made a major contribution to the development of analytical techniques of broad applicability to all types of crystals, whether they had a center of symmetry or not. It was a considerable step to bridging the gap between theory and practical application.

X-ray diffraction analysis involves the determination of the arrangement of atoms in crystals from which the molecular formula is derived directly. Determination of the molecular structure is important in that once the structural arrangement is understood, the substance itself can then be synthesized to produce useful products. This research occupies an almost unique position in science because the information it provides is used continuously in other fields. In fact, many phenomena in the physical, chemical, metallurgical, geological, and biological sciences are interpretable in terms of the arrangements of atoms.

J. Karle and I. Karle are still conducting research at NRL since joining the Laboratory in 1946. Their research plays a large part in the Navy's energetic materials program, which focuses on making explosives and propellants that are safer, more powerful, or both.

Impact

Methodologies for determining molecular structures are major contributions to science and technology. For example, they form the basis for the computer packages used in pharmaceutical laboratories and research institutions worldwide for the analysis of more than 10,000 new substances each year. A significant portion of structural research has direct application to public health, including the identification and characterization of potent toxins found in animals and plants, antitoxins, heart drugs, antibiotics, antiaddictive substances, anticarcinogens, and antimalarials.

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The Viking Program

Achievement

In 1946, NRL directed the development of a new sounding rocket called Viking, which was designed and built by the Glenn L. Martin Company. The rocket motor was built by the Reaction Motors Company, the firm that had just constructed the motor for the Bell X-1 aircraft, in which Chuck Yeager broke the sound barrier in 1947. Viking was the first rocket designed for essentially research purposes and the first to use a gimballed motor to control the direction of flight.[48]

The first successful launch of the Viking took place at the White Sands proving ground in 1949. Later in 1950, a rocket was launched from a ship, the USS *Norton Sound*, achieving an altitude of 106.4 miles.[49] This launching of such a large rocket from the deck of a ship had very important national security ramifications in that it was a step toward the eventual deployment of missiles at sea. In fact, *Life* magazine reported that Navy officials "had proved for the first time that big rockets, capable of carrying A-bombs several hundred miles, could be launched from the deck of a ship."[50]

In all, 12 Vikings were launched by NRL between 1949 and 1954, establishing many milestones: highest altitude of any research rocket at that time (136 miles); first measurements of temperature, pressure, and winds in the upper atmosphere; first measurements of the electron density in the ionosphere; and first high-altitude (approximately 100 miles) photographs of the Earth.

Impact

The Viking program established many scientific milestones, demonstrated the feasibility of sea-based missile systems, and took the first high-altitude picture of a hurricane in October 1954. This was the first color photograph successfully taken from such altitudes, and it initiated the interest of the weather service in high-altitude weather monitoring.[51] Finally, Viking paved the way for the historic Vanguard project, America's first satellite program.

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Synthetic Lubricants

Achievement

Soon after the introduction of gas turbine-powered aircraft in World War II, it became evident that new and better lubricants were required to take advantage of the potential capabilities of these engines. The new lubricants would have to retain sufficient viscosity to support bearing loading at 280° to 300° F and be stable enough oxidatively and thermally to withstand heat "soak back" temperatures of from 400° to 500° F. Because of NRL's previous success in developing synthetic lubricants for instrument bearings, the Navy Bureau of Aeronautics requested in 1947 that it undertake the development of lubricating oils for turbojet and gas turbines.

Responding to this request, W.A. Zisman, C.M. Murphy, and their colleagues conducted fundamental studies that related molecular structure to lubricating and temperature/viscosity properties. Structural guides, derived from those fundamental studies, permitted extending the useful temperature range of the oils.[52] As a result, NRL developed the first hydrocarbon ester fluids as lubricants that would perform acceptably at the high bearing operating temperatures in jet engines.

By the early 1950s, diester lubricants developed at NRL were in use in Navy turbine engine aircraft and soon were used by nearly all military and civilian turbine-powered aircraft. As turbine engine power requirements and operational temperatures increased, NRL was active in developing lubricants and lubricant additives to meet these more stringent conditions as well.

In addition to extending the high temperature range, instrument oils were also developed for service at –65° F to overcome the problem of losses resulting from the aircraft cannon freezing at the high altitudes that were newly reachable by jet aircraft at the time of the Korean War.[53]

Impact

The U.S. military needed new lubricants to be able to utilize turbine aircraft at their maximum performance, especially in combat. NRL research met this requirement. Essentially all turbine engines now used by military and civilian aircraft are lubricated with ester oils whose development was based on early research and development at NRL.

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Over-the-Horizon Radar

Achievement

During the late 1940s, NRL foresaw the need for detecting moving targets, including aircraft and missiles, at distances and altitudes beyond line-of-sight distances. Microwave radar as developed during World War II was limited in range by the curvature of the Earth. In 1950, while using the pioneering work it accomplished in 1926 (radio "skip distance" effect theory), NRL began to investigate the use of radar operating in the high-frequency (HF or short wave) portion of the radio spectrum to extend the range beyond the horizon. This is achieved by the refraction (bending) of radar waves when traveling through the ionosphere, which is located high above the Earth's surface. Using the ionosphere to bend the radar energy back to the Earth's surface can extend the range of a radar out to 2,000 nautical miles.

By 1955, NRL was operating on HF pulse doppler radar called MUSIC (Multiple Storage Integration Correlation). MUSIC was eventually able to detect missile launchings up to 600 nautical miles and atomic explosions up to 1700 nautical miles. With the use of a bank of reed filters, it could display multiple aircraft targets and the frequency spread of the backscatter.[54]

In 1961, based on the success with MUSIC, a high-power, high antenna-gain OTH radar known as MADRE (Magnetic Drum Radar Equipment) was installed at the NRL Chesapeake Bay field site. It was able to detect and track aircraft as they traveled across the Atlantic Ocean. With the NRL MADRE experimental radar, nearly all the fundamental capabilities of HF OTH radar were discovered and demonstrated: aircraft detection and tracking, ship detection, missile launch detection, nuclear test location, sea state determination, storm tracking, and vectoring aircraft to intercept.

Impact

NRL's development of OTH radar solved a critical military requirement where the horizon limit of conventional radar was overcome, giving an order of magnitude or more increase in useful range. This technology formed the technical base that led to the Air Force's AN/FPS-118 radar for continental air defense and the Navy's Relocatable Over-the-Horizon Radar, as well as influenced HF radar development in other countries of the world. HF OTH radar is the most cost-effective wide-area sensor available today.[55]

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Vanguard Program — The Rocket

Achievement

Between 1955 and 1959, NRL conducted the first American satellite program, called Vanguard. The program was initiated to represent the United States in the International Geophysical Year (IGY), a cooperative international scientific effort to study the physical properties of the Earth. The nation's leaders chose to participate in the IGY by placing an artificial satellite in orbit, and a competition was held to determine which government agency would build and launch the satellite. NRL's plan was selected, due in part to its success with the Viking program. The Laboratory's pioneering task was to design, build, launch, place into Earth-orbit, and track an artificial satellite carrying a scientific experiment. The contractor for the rocket project was the Glenn L. Martin Company.

The rocket successfully met the program's objective of putting a satellite into orbit during the IGY. The *Vanguard I* satellite was launched into Earth orbit on March 17, 1958, 5 months and 13 days after the Soviet Union launched *Sputnik I*, and about 6 weeks after the launch of *Explorer I*. Successfully designing and developing a three-stage rocket, with three brand new and unproven stages, on such a timely schedule was unprecedented. Experience in the DoD at that time showed that in missile programs it took more than 5 years from the start of a program to arrive at the date of the first successful launching; the Vanguard team achieved their objective in 2 years, 6 months, and 8 days.[56] Wernher von Braun, chief architect of the Redstone rocket, called it a miracle.[57]

Impact

The Vanguard rocket successfully met the program's objective of launching a scientific satellite into orbit during the IGY, and the rocket technology pioneered by Vanguard was used by later programs. The use of a "strapped down" gyro platform, the rotatable exhaust jets of the first-stage turbopump which ensured efficient roll control, and the C-band radar antenna beacon employed on the Thor-Able vehicle all originated with Vanguard. In fact, the Air Force used many design concepts from Vanguard's second and third stages in its Thor-Able booster. Finally, one of America's most versatile and reliable launchers, the Delta rocket, reflects much of Vanguard's design.[58]

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Vanguard Program — Minitrack and Space Surveillance

Achievement

Since a suitable satellite tracking system did not exist at the time of the Vanguard program, NRL developed the world's first satellite-tracking system (called "Minitrack") in 1956. This tracking network was later transferred to the Goddard Space Flight Center and formed the basis for the satellite tracking networks used by NASA.

Ironically, the Minitrack system first demonstrated its capabilities by tracking another nation's satellite. From October 5-26, 1957, NRL accurately predicted and tracked the orbits of the Soviet Union's *Sputnik I*. Three months later, NRL confirmed and tracked *Explorer I*, America's first orbiting satellite launched into orbit by the U.S. Army. Minitrack tracked the orbit of *Vanguard I*, launched on March 17, 1958.

After the Soviet launch of *Sputnik I*, the detection and tracking of foreign satellites orbiting over the United States became a major national security issue. As a result, the Navy Space Surveillance System (NAVSPASUR) was developed by NRL on a "crash basis" for the Advanced Research Projects Agency from 1958 to 1964 in order to detect and track such satellites. NRL was selected to develop this system primarily because of Minitrack's success. But unlike Minitrack, NAVSPASUR was designed to track satellites that transmitted signals and those that were "quiet." NAVSPASUR, now called the Naval Space Surveillance System, consists of nine bistatic radar sites stretching between southern California and Georgia and comprises a radar "fence" capable of detecting basketball-sized objects in orbit as high as 7,500 miles above the Earth.[59] The information gathered is used to warn the U.S. naval units of periods when they would be vulnerable to detection. By 1983, NAVSPASUR was a critical element in the North American Air Defense Command's Space Detection and Tracking System and was tracking more than 4,966 objects every day.

Impact

As the world's first satellite tracking system, the impact of Minitrack was significant, not only to the primary task of tracking the orbit of the Vanguard satellites, but also in tracking the orbits of the Sputnik and Explorer satellites. Later, the concept was employed by NRL in the design and development of NAVSPASUR, the primary system for maintaining surveillance of space objects and for warning U.S. Fleet units of periods of vulnerability to foreign surveillance satellites.

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Vanguard Program — The Satellites and the Science

Achievement

The *Vanguard I* satellite was successfully launched into Earth orbit on March 17, 1958. Although it was not the first U.S. satellite successfully launched, *Vanguard I* met the program's original objective of putting a satellite into orbit during the International Geophysical Year (IGY), a cooperative international scientific effort to study the physical properties of the Earth. *Vanguard I* achieved the highest altitude of any man-made vehicle to that time and established beyond doubt geologists' suspicions that the Earth is pear-shaped.[60]

A significant innovation in *Vanguard I* was the use of miniaturized circuits. It carried two radios and a temperature sensor and was the first satellite ever to use solar cells as a power source.[61] The solar cells developed by the Signal Engineering Laboratories, placed by Vanguard engineers on the satellite shell so as not to interfere with the functioning of the internal instrumentation, set a new standard of efficiency and account for the long operating life of the satellite.[62] *Vanguard I* orbits the Earth today as the oldest man-made satellite and it will remain in orbit well into the 22nd Century.

Vanguard II was placed in orbit on February 17, 1959, and was the first satellite designed to observe and record the cloud cover of the Earth. As such, *Vanguard II* was the forerunner of future meteorological satellites.[63]

Impact

The Vanguard program established landmark scientific achievements. Scientists at the National Academy of Sciences and NASA acknowledge the program as a progenitor of American space exploration. According to a National Academy of Sciences panel in 1958, "The overall scientific program developed for use with the Vanguard launching system has made possible the total program of space vehicle instrumentation, observation, and data reduction carried out under IGY auspices. Additionally, it has provided the original basis of the present expanding program of scientific experiments for space research for the U.S."[64]

Primary Reference Documents

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[62] Green, C.M. and Lomask, M., *Vanguard: A History* (NASA, Washington, DC, 1970), p. 254.

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SOLRAD I

Achievement

The SOLRAD (SOLar RADiation) program was conceived in the late 1950s as an improved means of studying the Sun's effects on the Earth, particularly during periods of heightened solar activity. Of prime interest were the effects of solar radiation on the ionosphere, which had critical importance to Naval communications. It was NRL's and the nation's longest continuing series of satellite projects dedicated to a specific research program. *SOLRAD I* was launched in June 1960, and ten more SOLRADs were fabricated by NRL and flown through 1976.

SOLRAD I was unique for many reasons: it determined that radio fade-outs were caused by solar X-ray emissions, verifying a theory of NRL's H. Friedman; it was one of the two satellites launched during the world's first multiple satellite launching; it was the world's first orbiting astronomical observatory; and it was the first satellite to be successfully commanded to shut off. On August 6, 1960, *SOLRAD I* recorded 6 of 18 minutes of the first solar flare recorded by an orbiting satellite and telemetered the information to a NASA tracking station. The data recorded throughout *SOLRAD I*'s active life shed new light on the relationships among sunspot activity, solar X-ray emission, and radio wave propagation.

Subsequent SOLRADs served as solar radiation monitors circling the Earth, on guard for any unusual solar disturbances that could have endangered the astronauts during the Apollo missions. Special SOLRAD operations for the *Apollo 8* moon mission began at the request of NASA in December 1968 when astronauts first circled the Moon and returned to Earth. Later, during July 1969, solar flare forecasts derived from data furnished by *SOLRAD 9* were used to safeguard *Apollo 11* astronauts and their communications systems during the historic first lunar landing mission. NRL furnished solar radiation data to the Space Disturbance Forecast Center of the Environmental Science Services Administration (now NOAA), which had the responsibility for determining the status of radiation hazards to the Apollo astronauts. *SOLRAD*s *9* and *10* provided these data throughout the Apollo and SKYLAB programs.[65]

Impact

NRL's SOLRAD series of satellites yielded important new scientific information on the Sun's effects upon the Earth's atmosphere. The new knowledge gained by the program also yielded practical, and in some cases critical, benefits to Naval communication and the U.S. manned space program.

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America's First Operational Intelligence Satellite

Achievement

The now unclassified *Galactic Radiation and Background I* (*GRAB I*) payload, an acknowledged co-flyer with the publicly recognized *Solar Radiation I* (*SOLRAD I*) scientific payload, was America's first operational intelligence satellite.[66] In June 1960, fifty-two days after a U-2 aircraft was lost on a reconnaissance mission over Soviet territory, the *GRAB I* satellite soared into orbit and began transponding space-intercepted electronic intelligence signals to Earth-bound signals intelligence stations.

GRAB I was the unique application of many emerging technologies. NRL's M.J. Votaw, previously with Project Vanguard, brought the technical experience and resources necessary to design, build, launch, and operate a satellite in space. R.D. Mayo supervised the design and development of the S-band antenna with crystal video receiver and ground receive equipment to collect signals from Soviet air defense radar. H.O. Lorenzen provided the overall technical direction, obtained intelligence community sponsorship, and led transfer of the technology into operational deployment. The notion of operating the antenna/detector reconnaissance technology in an orbiting satellite and collecting its transponded signal on magnetic tape was a breakthrough answer to CNO ADM Arleigh Burke's request for naval material bureaus and laboratories to consider how they could use space in their design ideas for the Navy.

With mission sponsorship by the Office of Naval Intelligence, NRL completed development of the satellite and its network of overseas ground collection sites. President Eisenhower approved the electronic intelligence (ELINT) program and its SOLRAD scientific experiment cover. The GRAB/SOLRAD payloads shared a ride into space with the Navy's third *Transit* navigation satellite as part of the world's first multiple-satellite launching. Field sites recorded *GRAB I* signals on magnetic tapes, which were couriered to NRL for evaluation and duplication. The National Security Agency (NSA) and the Strategic Air Command exploited the tapes for technical ELINT data and to support the Single Integrated Operations Plan.

Impact

The GRAB project provided proof-of-concept for satellite-collected ELINT. This was accomplished by demonstrating that a platform in outer space could collect as much as all other sea, air, and land-based reconnaissance platforms operating within the satellite's field of view, at a fraction of their cost, and at no risk to personnel. The output, initially overwhelming, stimulated invention by NRL and NSA of machine processing of digitized data using commercial computers. In searching the tapes for new and unusual signals, NSA found the Soviets were already operating a radar that supported a capability to destroy ballistic missiles. Such information could not be obtained by airborne reconnaissance, nor without enormous risk to human sources. The intelligence information gained from *GRAB I* had a profound impact on national security decisionmaking and on deterrence of nuclear war with the Soviet Union.

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Improved Aircraft Canopy and Window Materials

Achievement

NRL's interest in aircraft windows originated with the blow-out failures of combat aircraft canopies. These failures resulted from the inability of the canopy material to halt the propagation of cracks caused by impacts of sharp objects or by missile penetration.[67] In 1953, J. Kies applied NRL's pioneering research in fracture mechanics for the first time to a practical problem — the failure of combat aircraft canopies.[68]

Experiments by I. Wolock, then at the National Bureau of Standards and later with NRL, showed that craze cracking of acrylic could be eliminated by hot stretching, a result which led Kies to the idea that hot stretching could add to the toughness of aircraft windows. Kies worked with commercial manufacturers of acrylic material (e.g., Rohm and Haas) and used fracture mechanics to ascertain the toughness of the material. In the course of the work, NRL shattered hundreds of aircraft canopies by projectile impact, and then carefully reassembled them to allow crack paths to be traced.[69] Kies pointed out that the critical stress for a given crack size depended only on the product G_cE, which could be directly computed from the applied stress and crack size for the test.

The response of aircraft engineers concerned with testing stretch-toughened glazing materials was to express their fracture test results in values they termed K (K for Kies).[70] Kies' work is also incorporated in design criteria for aircraft plastic glazing materials issued jointly by the Departments of Commerce, Navy, and Air Force.

Impact

NRL worked cooperatively with the Air Force and with commercial manufacturers to introduce stretched acrylic plastic for military canopies with increased toughness, reduced weight, and prolonged service life. This material is now employed in military and civilian aircraft, thereby reducing a once significant source of fatal accidents.

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Purple-K-Powder

Achievement

Prior to the development of potassium bicarbonate dry chemical extinguishing agent, or "Purple-K-Powder" (PKP), hydrocarbon fires were extinguished using either sodium bicarbonate dry chemical powder or protein foam. The dry chemical was effective on three-dimensional and "hidden" fires (e.g., debris from aircraft crash), but provided no protection against reflash. Protein foams were used to extinguish fuel spill or in-depth liquid pool fires. The thick foam blanket provided reflash protection by excluding oxygen from the fuel surface, but foams were ineffective on 3-D and hidden fires. The agents could not be used in combination because the foam bubbles were chemically attacked and destroyed by commercially available dry chemicals. The first step in developing an optimum approach was to develop a superior, foam-compatible dry chemical.

In 1959, a series of investigations by NRL in the area of chemical flame extinction gave birth to Purple-K-Powder. Powdered bicarbonate of soda as a flame-halting agent had been employed for many years, but its action had never been satisfactorily explained. Working with other investigators, NRL conducted fire tests with many powdered substances, which helped to clarify the chemical actions involved. This work came to the conclusion that the substitution of the potassium ion for sodium extended the flame-quenching efficiencies of the chemical powders by a factor of two.[71] This meant PKP extinguished a fuel fire in half the time or extinguished twice as much fire as before. Ensuing industry efforts resulted in production of surface coatings that allowed PKP to be compatible with foams.

Impact

The development of Purple-K-Powder represented a major advancement in the state of the art for flammable liquid fire protection. PKP became used throughout the Navy and in U.S. municipal and industrial fire protection operations, and thereafter throughout the world. It is the only dry chemical agent recognized by the National Fire Protection Association for airport crash rescue firefighting.

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Improved Boilerwater Treatment

Achievement

Naval 1200 psig steam propulsion boilers are subject to the damaging effects of corrosion and scale formation on the watersides if a proper boilerwater treatment is not applied. Tube failures due to acid corrosion and scale formation are two major concerns that in the past were satisfactorily controlled by a low phosphate/free caustic treatment. However, accumulations of suspended solids required mechanical and chemical cleaning. Both types of cleaning require ships' boilers to be out of service and increase the crew's workload.

NRL and the Naval Ship System Engineering Station (NAVSSES) started investigations into new water treatments to clean, in situ, Naval high pressure boilers in the late 1960s. NRL investigated the thermal stability chemistry of ethylenediaminetetraacetate (EDTA) salts as possible active components of a boilerwater treatment for high pressure boilers. Nuclear magnetic resonance was used to study the chemistry of EDTA salts and free acid under various thermal conditions. The reported kinetics of the chemical reactions indicated the amount of EDTA to add to the boiler on a continuous basis. This research was the guide that R.L. Dausuel, Jr., NAVSSES, used to introduce EDTA into operating Navy boilers.[72]

This group effort led to a final treatment that included the addition of hydrazine to stabilize the EDTA solutions upon their addition to the boilers. After excellent results from four trial ships, the chief engineer of the Naval Sea Systems Command directed the implementation of a boilerwater treatment based on an Na_4EDTA and hydrazine process. Results of shipboard testing demonstrated that use of the Na_4EDTA to clean, in situ, high-pressure steam boilers could extend the normal 1,800 hours of operation between cleanings to 15,000 to 20,000 hours. In addition, the passivated surfaces within the steam systems treated with Na_4EDTA would be beneficial when boilers were shut down for long periods of time.

Impact

NRL's basic research was instrumental to keeping Navy ship boilers in service for much longer periods and in reducing the costs associated with frequent cleanings. In addition, industrial water treatment plants found promise in the Navy's approach.[73]

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Fracture Test Technology

Achievement

While NRL's G. Irwin was concerned primarily with the basic science of fracture, his colleague W.S. Pellini established methods for prevention of fracture based on experimental methods. Pellini developed engineering approaches for design and material selection in structures based on metallurgical principles. His work solved the mystery of brittle fractures of World War II *Liberty* ships, in which entire ships sometimes fractured in calm water at dockside, and is still relevant in the age of high-performance ships, aircraft, and missiles.

The test methods developed by NRL are the Dynamic Tear Test; the Drop-Weight Nil-Ductility Transition Temperature Test (DWT-NDT, standardized by the ASTM in 1963 and used along with the Fracture Analysis Diagram for design of steel structures worldwide); the Explosion Bulge Test; and the Explosion Tear Test. Such tests were incorporated into materials procurement and fabrication specifications for construction of critical submarine and surface ship components.[74] A prominent example is the selection of materials for submarine pressure hulls that had to withstand local deformations from explosive attack, without crack extension. NRL worked with the Navy's ship and submarine materials and design codes to develop methods for evaluating materials, weldments, and welding processes. These methods, based on modeling, established the requirements for qualifying welds, welders, and new companies for the construction of submarine pressure hull structures.

The DWT-NDT proved the fracture resistance of HY-80 steel was superior to conventional steels, and the fully plastic performance of welded HY-80 plates in the Explosion Bulge Test convinced the Navy that HY-80 should be used for submarine hulls and for any other critical application.[75] In addition, two Deep Submergence Rescue Vehicles that were built with pressure hull material certified to be reliable as measured by fracture mechanics methods were put into the Fleet.

Impact

For more than 20 years, NRL was recognized as the leading international center for the development of structural integrity technology. During this time, the Navy relied upon NRL's expertise to assure the structural integrity of aircraft, ships, and submarines, and in doing so, to safeguard their crew members. These techniques also increased the performance of Naval vehicles, providing such payoffs as reliable deployment of deeper running submarines.

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Deep Ocean Search

Achievement

On April 10, 1963, the nuclear submarine USS *Thresher* (SSN 593) was lost in deep water 260 miles east of Boston, Massachusetts, with 112 crew and 17 civilian technicians. The loss of the submarine and its complement was a deep shock to the Navy and to the country.

In an effort to determine the reasons for the loss, NRL applied deep-towing technology, developed years earlier for underwater acoustic research, to the deep seafloor search for the *Thresher*. However, the search was terminated in September 1963 with the onset of bad weather.[76] On May 18, 1964, the task group began new search operations. To augment its search capability, NRL had acquired the USNS *Mizar*, a retired cargo ship suited for launching and towing the deep-towed instrument vehicle, or "fish" as it was called. NRL's "fish" included a set of three cameras to photograph the wreckage, a side-scanning sonar to probe beyond camera range, two strobe lights, a magnetometer to locate the *Thresher* pressure hull, a transponder, a sonar pinger to measure the "fish's" altitude, and a telemetry system. This unmanned vehicle, towed by *Mizar*, detected the *Thresher* hull after only eight hours of bottom operations. NRL's photographs were later assembled into a photomosaic of most of the major parts of the sunken submarine.[77]

After NRL's success in the *Thresher* search, the Laboratory was called upon to locate and recover a lost H-bomb off the coast of Spain in 1966, locate and photograph the lost submarine USS *Scorpion* (SSN 589) in 1968, assist in the recovery of the deep submersible Alvin in 1969, and locate and photograph the lost French submarine *Eurydice* in 1970. NRL's emergency search mission was transferred to other Navy organizations in 1980.

Impact

NRL-developed ocean search technology now resides in other government and private organizations. According to a 1966 commendation from the Marine Technology Society, NRL was responsible for "pioneering new techniques" and had "established a methodology for future ocean engineering." Years later, after the Titanic was located by Dr. Ballard's team, a former Navy Supervisor of Salvage stated before Congress that "the superb work of the scientific teams from NRL...led the way for the [Titanic] search operation in the North Atlantic."[78]

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NAVSTAR GPS

Achievement

The NAVSTAR Global Positioning System (GPS) is designed to provide precise navigation data to military and civilian users by means of a constellation of 24 satellites. NAVSTAR is based on NRL's TIMATION (TIMe/navigATION) research program, begun in 1964. R. Easton is recognized for conceiving the idea of the time-based navigational system, which eventually led to the GPS. NRL tested TIMATION concepts by developing and launching two small experimental satellites, *TIMATION I* and *TIMATION II*.

NRL launched the *TIMATION I* satellite on May 31, 1967, and the *TIMATION II* satellite in 1969. *TIMATION I* demonstrated that a surface vessel could be positioned to within two-tenths of a nautical mile and an aircraft to within three-tenths of a nautical mile using range measurements from a time-synchronized satellite. The TIMATION program proved that a system using a passive ranging technique, combined with highly accurate clocks, could provide the basis for a revolutionary navigation system with three-dimensional coverage (longitude, latitude, and altitude) throughout the world.

In 1973, NRL's program was merged with an Air Force program that was investigating similar requirements to form the NAVSTAR GPS program. *TIMATION III* was redesignated the *Navigation Technology Satellite One* (*NTS-1*), and was launched in 1974 in connection with the new NAVSTAR effort. *NTS-1* had the distinction of carrying the first atomic clocks into orbit. *NTS-2* was launched in June 1977 as the first NAVSTAR satellite.[79]

Impact

NAVSTAR's military and commercial applications are revolutionary and too numerous to enumerate here. In 1993, the National Aeronautic Association selected the GPS Team composed of NRL, the U.S. Air Force, Aerospace Corp., Rockwell International, and IBM Federal Systems Co. as winners of the 1992 Robert J. Collier Trophy, the most prestigious of all aviation awards in the U.S. The citation accompanying the trophy honors the GPS Team "for the most significant development for safe and efficient navigation and surveillance of air and spacecraft since the introduction of radio navigation 50 years ago." In 2005, Roger L. Easton received the National Medal of Technology from the President for "his extensive pioneering achievements in spacecraft tracking, navigation and timing technology that led to the development of the NAVSTAR - Global Positioning System."

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Aqueous Film-Forming Foam

Achievement

NRL, beginning in the early 1960s, conducted research on fire suppression that eventually led to one of the most far-reaching benefits to worldwide aviation safety — the development of Aqueous Film-Forming Foam (AFFF). AFFF achieves rapid extinguishment of hydrocarbon fuel fires and has the additional property of forming an aqueous film on the fuel surface that prevents evaporation and, hence, reignition of the fuel once it has been extinguished by the foam. The film also has a unique, self-healing capability whereby scars in the film layer caused by falling debris or firefighting activities are rapidly resealed.

The initial concepts for AFFF came from NRL's R.L. Tuve and E.J. Jablonski, who patented the first formulation for use in a twinned agent firefighting apparatus that combined Purple-K-Powder (an earlier NRL development; see page 27) and AFFF. Although NRL was responsible for the original concepts and formulations, it was necessary to elicit the aid of the chemical industry to synthesize the fluorinated intermediates and agents to achieve improvements in formulations. The Minnesota Mining and Manufacturing Co., now 3 M, contributed considerably to the success of the development of AFFF.

In honor of his work in developing AFFF, the Society of Fire Protection Engineers International awarded (posthumously) the Arthur B. Guise Medal to E.J. Jablonski in 1990 for "eminent achievement in the advancement of the science and technology of fire protection engineering."

Impact

Following the destructive fires aboard the aircraft carriers USS *Forrestal* and USS *Enterprise*, the Navy sought more effective firefighting agents. NRL met this Fleet requirement with the development of AFFF. In the military, AFFF firefighting foam is now on all Navy aircraft carriers, and is used by all branches of the U.S. armed forces and NATO members. The agent is also recognized by international standards organizations for the protection of civilian airfields, refineries, and fuel tank farms, where potentially catastrophic fuel fires can occur. AFFF is in the inventory of almost all fire departments in the United States and in many fire departments throughout the world. In fact, two foam units from the Metropolitan Washington Airports Authority fought the fires caused by the 9/11 terrorist attack on the Pentagon.[80]

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[80] Weiger, P., "After-Action: Pentagon Report," NFPA Journal (Nov/Dec 2002), p. 36.

Nuclear Reactor Safety

Achievement

A major application of NRL's fracture-test technology was the Laboratory's participation in the Heavy-Section Steel Technology Program conducted by the Nuclear Regulatory Commission. The technical issue was to determine the safety of nuclear reactor pressure vessels fabricated from 12-inch thick steel, as a function of the thickness and temperatures. NRL's W.S. Pellini and F.J. Loss built the apparatus and conducted experiments on full-thickness specimens to demonstrate the safety of the vessels. The program lasted several years and attracted international attention. The ASME Code rules for the operation of nuclear pressure vessels are based on the results of that program.[81]

In the early 1960s, NRL demonstrated the potentially severe embrittlement of nuclear reactor steels to be a function of neutron exposure and irradiation (service) temperatures. While emphasizing light-water reactor pressure containment steels and their modes of failure after neutron exposure, the properties of other reactor component alloys were studied as well. Broad interest in NRL's work led to support by the Atomic Energy Commission and the Army. This work is believed by most nuclear safety authorities to be a primary basis for assurance against catastrophic failure of radiation containment. In 1975, a definitive book by NRL's L.E. Steele, *Neutron Irradiation Embrittlement of Reactor Pressure Vessel Steels*, was published and became a landmark guide for specialists worldwide.[82]

Impact

All military and civilian power reactors that feature a steel pressure shell are designed or operated, or both, on the fracture principles developed by NRL.[83] And, the Laboratory's work in radiation embrittlement in reactor pressure vessel steels led to the production of radiation-resistant steels, which are applied in new reactors throughout the world, and in the assurance of reactor containment safety in older reactors.

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[81] E.A. Lange, "Personal Account of Research Conducted Between 1950 and 1980 in the Metal Processing and the Strength of Metals Branches," in *Materials Science and Technology Division History*, NRL/PU-6300-93-240 (May 1993), p. 127.

[82] Steele, L.E., International Atomic Energy Agency Technical Report 163; quoted in *Materials Science and Technology Division History*, p. 131.

[83] Whitman, G.D., Robinson, G.C., and Sanolainen, A.W., "Technology of Steel Pressure Vessels for Water-Cooled Nuclear Reactors," ORNL-NSIC-21, December 1967, Chapter 7 uses NRL Report 6598, November 1967; cited by Irwin in *Materials Science and Technology Division History*, p. 101.

Linear Predictive Coder

Achievement

The Linear Predictive Coder (LPC) is a means to represent the speech spectrum efficiently. In the LPC representation of speech, the speech spectral envelope is represented by an all-pole spectrum. In 1973, NRL's G.S. Kang developed the world's first LPC prototype capable of operating in real time to encode speech at low data rates. NRL's efforts generated an impetus to modernize DoD tactical secure voice communication equipment. Subsequently, NRL incorporated the LPC concept into the DoD Advanced Narrowband Digital Voice Terminal (ANDVT) that was under development at the time. Later, Kang incorporated the ANDVT voice encoding algorithm in Federal Standard 1015.

The computational steps required to execute LPC processing were enormous for 1970-technology standards. In fact, it was doubted that LPC could be implemented as a voice communication device.[84] But, in 1973, NRL was successful in implementing a real-time LPC telephone operating at 2400, 3600, and 4800 bits per second because the Laboratory had developed a computationally efficient iterative solution to the LPC analysis.

Impact

NRL's development of the LPC brought a complete upgrading of military tactical secure voice communication equipment in the 1970s. The new LPC-based ANDVT replaced the old channel vocoders. Currently 40,000 ANDVTs have been deployed by the Navy, Air Force, Army, Allied Forces and other government agencies to support tactical secure voice communications. Even today, nearly twenty-five years after initial deployment, the ANDVT featuring the NRL-developed LPC is still the DoD's only deployed tactical secure telephone operating at 2400 bits per second.

Primary Reference Documents

- Kang, G.S., "Application of Linear Prediction Encoding to a Narrowband Voice Digitizer," NRL Report 7774, 1974.

[84] Moye, L.S., "Digital Transmission of Speech at Low Bit Rates," (British) *Electrical Communication*, Vol. 47, No. 4, 212-223 (1972).

Submarine Habitability

Achievement

In the 1950s, as the age of the nuclear submarine emerged, the requirement grew for extending the capabilities of closed-cycle atmospheres for periods up to 90 days. The need for new atmosphere habitability capabilities was evident when NRL participated in a scientific cruise of the first nuclear submarine, USS *Nautilus*, in 1956. Its atmosphere was found to be "loaded" with pollutants, such as carbon dioxide, carbon monoxide, hydrogen, and hydrocarbons. NRL formed a team to solve the problem. In the 1950s and 1960s, this effort led to the CO/H_2 Hopcalite burner, the monoethanol amine CO_2 scrubber, and the adsorbent carbon bed. The major source of the hydrocarbons was paint thinners. As a result, painting was prohibited immediately prior to submergence and during deployment.

It was also apparent that an analytical instrument was needed to monitor contaminants.[85] In the 1970s, NRL convinced the Navy that mass spectrometry was the technique of choice for atmosphere analysis onboard nuclear submarines. NRL evaluated prototype systems that became the basis of the Central Atmosphere Monitoring System Mark-I (CAMS-I). These systems were installed onboard all nuclear submarines, replacing previous poorly performing analyzers. Later, NRL's research capabilities in mass spectrometry were used to formulate the design of the next-generation analyzer, the CAMS-II. NRL directed the development, laboratory testing, and at-sea trials of the prototype. The CAMS-II is installed in Trident and Seawolf class submarines. NRL was also successful in transferring this technology to industry and in convincing the British Navy to use the CAMS-II aboard Royal Navy submarines.

Impact

Several NRL technologies led to the purification of submarine atmospheres. CAMS replaced atmosphere analyzers that were always on the "top ten" problem list of submarines. Combined, these technologies enable the Navy to operate its submarine fleet on extended deployments and at the same time be assured as to the safety of their atmospheres. The commercial version of CAMS, developed by Perkin Elmer for IBM,[86] has been used in semiconductor processing facilities to provide continuous monitoring of a variety of hazardous materials. The advantages of CAMS are its ability to measure many different atmosphere constituents, from part-per-billion to one hundred percent levels, and its reliability.

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[85] DeCorpo, J.J., Wyatt, J.R., and Saalfeld, F.E., "Atmospheric Monitoring in Submersibles," *ASME 80-ENAs-31* (1981).

[86] Krieger, J.H., "System Continuously Monitors Air Quality in Industrial Process Sites," *C&EN*, August 12, 1985.

Flux-Corrected Transport

Achievement

In the late 1960s, NRL conducted theoretical and computational investigations of high-altitude nuclear effects (HANE) for the Defense Nuclear Agency. During 1970 and 1971, in the process of performing this work, NRL developed an entirely new technique for solving fluid dynamic continuity equations on a computer.

The technique, flux-corrected transport (FCT), made possible accurate calculations of shock and steep gradient phenomena by eliminating the oscillations, ripples, and numerical diffusion that had plagued all other techniques for decades. In addition to the HANE research, FCT has been employed in missile silo design, naval oceanography, nonacoustic antisubmarine warfare, and atmospheric communications research. Other applications include facilitating research in civil hydrodynamics and water resources, mine safety, atmospheric pollution transport, supernova explosions, solar weather prediction, laser and ion-beam fusion, aerodynamics, and base and force protection against weapons of mass destruction.

More recent applications include the 3-D urban aerodynamics computations for CT-Analyst™ and urban defense for weapons of mass destruction.

Impact

With over 1,000 citations, the original paper on FCT was NRL's most cited publication during the period between 1973 and 1988. This technique has been adopted by over 500 computational laboratories, universities, and companies dealing with fluid flow problems that impact military operations, civil projects, and public health and safety. A conference entitled "High-Resolution Schemes for Convection Dominated Flows: 30 Years of FCT" was held in Dortmund, Germany, in September 2003, to commemorate this development.

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Fiber-Optic Interferometric Acoustic Sensors

Achievement

In 1977, NRL demonstrated the world's first fiber-optic interferometric acoustic sensor.[87] Based on this work, NRL received the first U.S. patent awarded for an optical interferometric sensor to measure external fields. This device focused on acoustic fields. From the beginning, it was viewed as a generic device in that it would be capable of responding to other external perturbations (e.g., electric field, magnetic field, and temperature) depending on the design of the fiber coating or mounting structure.

NRL's work launched Navy, DoD, and national interest in fiber-optic acoustic sensors in particular, and fiber-optic nonacoustic sensors in general. In 1978, based on the fiber acoustic sensor results, NRL conducted the first Navy / DoD program in fiber-optic sensor systems (FOSS) — the vanguard of a rapidly growing interest in fiber interferometric sensors. NRL was the leader in this technology in the late-1970s to early-1980s. Other organizations, such as the Naval Underwater Warfare Center, the Naval Surface Warfare Center, and Litton, have since joined NRL in developing systems based on these sensors.

A number of sensor system technologies based on interferometric fiber acoustic sensors have been successfully demonstrated. One such system is an all-optical towed array (AOTA) with a full complement of fiber-optic acoustic sensors. In 1986, fiber-optic acoustic sensors were first tested at sea. Based on the results, an AOTA Advanced Technology Demonstration was initiated. Successfully completed in 1990, it met all performance goals and showed that the concept was a cost-effective alternative to piezoceramic technology.

Impact

NRL's original invention, and the subsequent FOSS program, led to the now ubiquitous presence of fiber-optic sensor devices. These devices resulting from NRL's pioneering work have been exploited in numerous sensor-related areas, including acoustic, magnetic, electric, thermal, vibration, and flow applications. Commercial versions of these sensors have been applied to traffic control, medical care, construction safety, and seismology. Their military applications are also numerous. For example, the fiber-optic Lightweight Wide Aperture Array is deployed on the Navy's new *Virginia*- class nuclear submarines.

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- U.S. Patent No. 4,648,083 to Giallorenzi, T.G., "All-Optical Towed and Conformal Arrays," March 3, 1987.

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[87] The possibility of incorporating optical fibers into bulk interferometers to detect weak acoustic signals was also demonstrated independently by Cole et al. in November 1977 (Cole, J.H., Johnson, R.L., and Bhuta, P.G., *Journal of the Acoustical Society of America*, Vol. 62, 1136 (1977)). (NRL published its paper in July 1977.)

Semi-Insulating Gallium Arsenide Crystals

Achievement

In the 1970s, NRL invented and developed a liquid-encapsulated Czochralski (LEC) method of compounding and growing high-purity single crystals of gallium arsenide (GaAs) that were semi-insulating in nature without the need for doping. Because of their high purity semiconductor and semi-insulating properties, wafers made from these crystals could be used simultaneously as a dielectric and ion implanted active semiconductor layer material to produce high performance microwave and millimeter wave devices and integrated circuits. This development was important because transistors and microcircuits made of silicon, the most common semiconductor material used at the time, operated poorly at microwave frequencies. NRL performed the basic process development, demonstrated the principles for achieving the high-purity semi-insulating GaAs substrate, and was instrumental in transferring the technology to industry for commercialization.

This cost effective method of GaAs wafer production was important because it led to the early adoption of high performance GaAs devices and monolithic microwave integrated circuits (MMICs) in military microwave and millimeter wave systems.

Cost reduction is also critical to the competitiveness of U.S. companies. NRL's technology was adopted by major U.S. industrial firms, such as Rockwell International, Westinghouse, Texas Instruments, and Hughes Research.[88] In commending NRL's achievement, one U.S. company claimed that in 1980 approximately 100% of the GaAs device industry was in Japan, but that in 1997, the GaAs integrated circuit industry would realize sales of $447 M, with American companies representing 65% of that total.[89]

Impact

NRL's technology enabled GaAs monolithic microwave integrated circuit technologies. Military systems using these technologies are all forms of military radar systems, electronic warfare systems, communications systems, satellite systems, and many weapons systems such as HARM, Phoenix missile, AIM-9L, and AMRAAM. Commercial uses are ubiquitous and include weather and navigation radar, communications systems including cellular and satellite systems, and wireless LANs. The technology demonstrated audited savings to the military for the 10-year period from 1979 to 1989 of over $560 million (in 1986 dollars).[90] This is all the more impressive given that the original investment in NRL's research was $528,000.[91]

Primary Reference Documents

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[88] Presidential Letter of Commendation to H. Lessoff, nomination of 1985, awarded by President Reagan in 1988.

[89] Letter to H. Lessoff from J. Vaughan (Vice President for Business Development), M/A-COM, September 21, 1997.

[90] Commander, NAVAIRSYSCOM.

[91] Commander, NAVAIRSYSCOM, Letter of Commendation to H. Lessoff and E. Swiggard (March 3, 1986).

Super Rapid-Blooming Offboard Chaff

Achievement

NRL developed the first wide spread decoy system applied to all major Navy surface combatants. The MK-36 and MK-182 cartridge was successfully operationally evaluated in 1977. Because of the operational success of this system, a follow-on international program was established to provide the continual product improvements that result from ongoing innovation. This international program led to the successful development of the MK-214 and MK-216 cartridges, which entered the Fleet in 1987 and 1988, respectively, and which are in current use. The super rapid-blooming offboard chaff (Super RBOC) system and its family of decoys will be used by the U.S. Navy and its allies for many years.

Impact

Super RBOC and its family of decoys significantly improved the Navy's capability to conduct electronic warfare from its surface combatants. It is a major advancement in the state of the art in its ability to rapidly produce an alternate target for the protection of ships against anti-shipping cruise missiles. With the extensive proliferation of the cruise missile threat throughout the world, this solution was especially timely and critical to the survivability of the Fleet.

Primary Reference Documents

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- "The Electronic Warfare Suite for the USS *NEW JERSEY*," NRL Memorandum Report 4841, July 1982.
- "NATO SEA GNAT Radio Frequency (RF) Seduction Cartridge," Commander Operational Test and Evaluation Force Report 3960 (621-1-OT-II), October 3, 1984.

Fixed-Wing Airborne Gravimetry

Achievement

Measurement and analysis of the spatial variations in the gravity field of the Earth are useful from both geologic/geophysical and geodetic perspectives. Gravity data serve in the first case as a remote sensing probe of shallow and deep mass distributions beneath the surface of the ocean or land, an important tool for economic geology and basic geophysical research. In the second area, geodesy/gravity data are used to establish the shape and figure of the Earth. Geodetic quantities are of critical operational importance to the Navy, primarily as corrections to high-accuracy inertial navigation systems in submarines and ballistic missiles. Over the years, enormous efforts and expenditures have been devoted to shipboard and terrestrial gravity surveys to meet Navy requirements.

Airborne gravimetry had long been a desirable goal because of the lower costs, rapid collection, and access to logistically difficult areas made possible by airborne surveying techniques. However, the extremely poor signal-to-noise characteristics of airborne gravity measurements defeated numerous attempts since the 1950s by government, academic, and industry researchers to provide airborne data of useful accuracy and resolution. It was found possible to acquire data at low speeds in helicopters, however their range was too limited and their costs too high to make them preferable to traditional ship and land survey methods.

In 1979, NRL began a program in airborne gravimetry from long-range, fixed-wing aircraft capable of meeting Navy requirements. The research program required the development of extremely accurate three-dimensional aircraft positioning, specialized aircraft operational techniques, and improvements to gravimeter technology. This program resulted in the world's first successful demonstration of accurate fixed-wing-based airborne gravity measurements. The 1981 field test of the prototype measurement system achieved accuracies of 2 to 3 parts per million on several profiles over an Atlantic gravity test range at aircraft speeds of 250 knots. Development of the system and techniques continues to the present day.

Impact

The NRL long-range airborne gravity measurement system is unique and provides required data for Navy and other DoD tactical and strategic systems that cannot be acquired in any other way.[92] Airborne gravity data are now being collected worldwide in support of operational requirements for Trident submarines, ballistic missiles, and B-2 and F-117 aircraft.

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REGIONAL CONFLICT AND TERRORISM

Specific Emitter Identification

Achievement

Specific emitter identification (SEI) provides electronics intelligence (ELINT) signal collection platforms with the capability to identify uniquely a radar transmitter with such accuracy as to make it possible to assign a "fingerprint" to that particular signal. In using SEI techniques, systems with a radar transmitter can be cataloged and tracked, and the data interchangeability between SEI systems allows a signal to be collected by one system and then "handed off" to another system for tracking. For example, SEI can be used to covertly track a contraband transport whose signal of interest can be collected by an aircraft and then transmitted electronically to a ship for subsequent tracking.

On April 14, 1982, R. Goodwin was the recipient of the Navy Superior Civilian Service Award. He was cited for:

> "performing and directing the research and development efforts that led to the achievement of an important, new Navy capability in real-time pulsed-emitter characterization."

In June 1993, the National Security Agency (NSA) recognized the superior capability of NRL's SEI concept and equipment after a competition among numerous participants from industry and other service laboratories.[93] The NSA test served as an impartial means for selecting an SEI methodology for use as a national standard. As a result of the test, NSA issued a message (DTG 011440Z, June 1995) that stated in part, "Accordingly, NSA has selected the Naval Research Laboratory processor (L-MISPE) to be the standard for conducting SEI/UMOP collection operations...."

Since that decision, SEI platforms have been very successful at cataloging and tracking platforms of interest. In one application, a library of over 300,000 specific radar signals has been compiled. This library is shared among the sites to aid in performing tactical intelligence and surveillance tasks.

Impact

SEI identifies any radar by its unique characteristics with such accuracy as to "fingerprint" it. In fact, it can distinguish between identical models produced off the same assembly line. With SEI systems deployed on ships, aircraft, submarines, and ground sites, NRL's technology has had significant warfighting impact. It saw combat action in Kosovo and in Operation Iraqi Freedom. Furthermore, Coast Guard vessels, Naval warships, and aircraft have used it to support drug interdiction, enforce treaties, and monitor the movement of materials used in weapons of mass destruction.

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[93] Christiansen, R.M., et al., "Assessment of L-MISPE Performance in Musketeer Dixie II," NRL Memorandum Report 7404-93, February 14, 1994.

[94] This is Goodwin's original patent disclosure for emitter feature extraction and use for SEI. Since the abstract was classified, no patent was pursued.

Deep Space Program Science Experiment (Clementine)

Achievement

The Deep Space Program Science Experiment (Clementine) program was a highly successful lunar mapping mission that tested new spacecraft hardware. During the 1980s, the Ballistic Missile Defense Organization (BMDO) developed advanced sensor and component technologies for missile defense systems. In 1991, a joint NASA/DoD study concluded that a collaborative deep space mission could test these developments and provide a significant science return. The DoD's goals were to test lightweight miniature sensors and components by exposing them to a long-duration space environment while obtaining imagery of the Moon and the near-Earth asteroid, Geographos. The BMDO tasked NRL with responsibility for mission design, spacecraft engineering, spacecraft manufacture and test, launch vehicle integration, terrestrial support, and flight operations.

In 1994, NRL put a satellite, equipped with a sensor payload, into orbit around the Moon. The spacecraft successfully used much newly developed hardware, including imaging sensors provided by the Lawrence Livermore National Laboratory. A high-quality mapping mission of the lunar surface was completed with outstanding success — a complete imaging of the lunar surface (1.8 million images) in eleven discrete wavebands with coarse altimetry over most of the lunar surface.

This imaging of the Moon's surface was a great success in its scientific returns: relative positions of widely separated lunar features could be accurately determined for the first time, including those on the Moon's far side; some regions in the lunar south pole were imaged with good resolution for the first time, with some data indicating the presence of ice; and complete multispectral imaging provided information on local mineral composition over the entire lunar surface. These images helped resolve issues such as the character and evolution of the primitive lunar crust, thermal evolution of the Moon and lunar volcanism, and the impact record and redistribution of crustal and mantle materials. Clementine's images are available for students everywhere to explore in a 3-D interactive environment on the Internet.[95]

Impact

With Clementine's success, the U.S. returned to the Moon for the first time since the end of the Apollo lunar missions. NRL's satellite demonstrated that the goal of "faster, better, cheaper" was attainable: it was built in only 22 months (less than half the usual time) for 1/5 the usual cost for similar space probes.[96] The probe was so simple to operate that its mission control center comprised eight engineers working in a warehouse in Alexandria, Virginia.[97] As for the presence of ice on the Moon, NASA's Lunar Prospector mission in 1998 found evidence of ice at both lunar poles.[98]

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[95] NASA News Release 05.56AR, 26 October 2005.

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[97] Excerpt from the *Discover* Magazine Award for Technological Innovation (1995)

[98] NASA Press Release, "Lunar Prospector Finds Evidence of Ice at Moon's Poles," (# 98-38), March 5, 1998.

Polar Ice Prediction System

Achievement

The Polar Ice Prediction System (PIPS) is the U.S. Navy's numerical, model-based, sea ice forecasting system. PIPS 1.0 went operational in 1987. It executed daily, 120-hour forecasts of ice thickness, ice drift, and ice concentration (including ice edge) for the Arctic and the Barents and Greenland Seas. Two additional regional forecast systems for the Barents and Greenland Seas became operational in 1989 and 1991, respectively. These models also made 120-hour forecasts of the same conditions as PIPS 1.0, but at five times the resolution. PIPS 2.0 became operational in 1995 and superseded all earlier forecasting systems. It is the first fully coupled, operational, ice-ocean nowcast/forecast system in the world encompassing all sea-ice covered regions in the northern hemisphere. It combines the Hibler ice model technology of the earlier PIPS with a Bryan-Cox ocean model to provide more accurate 5-day ice forecasts.

PIPS' use of remotely sensed data from assimilation in ice/ocean prediction is also a first. Although satellite data have previously been used by the high-latitude scientific community for model validation and verification purposes, NRL's team is the first to make use of satellite-derived ice data (ice concentration) as part of a data assimilation technique used to initialize daily ice/ocean forecast systems. The value of this capability has been recognized by other international forecasting centers, such as the U.K. Meteorology Office, by requesting this technique for incorporation into their own forecast systems.

PIPS 2.0, built on technology of the late 1980s and early 1990s, is scheduled to be replaced by PIPS 3.0. This coupled ice-ocean forecast system will consist of the recently developed Los Alamos ice model, CICE, coupled to the latest in Navy operational global ocean forecasting technology, the Global NCOM (Navy Coastal Ocean Model). The PIPS 3.0 multi-category ice thickness and improved ice ridging capability will provide more accurate forecasts of ice thickness, concentration and ice drift.

Impact

Accurate ice forecasts are important to the U.S. Navy operations. NRL's PIPS (PIPS 1.0 through PIPS 2.0) provided a major advance to the state of the art in operational sea-ice assimilation and forecasting. These were the first of their kind, real-time, operational capabilities in the world and are still unequaled today. PIPS provides operational guidance to the National Ice Center (a joint Navy, National Oceanographic and Atmospheric Administration, Coast Guard organization) in its civilian and military forecasts of high-latitude ice conditions.

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Optical Immunoassays and Sensors

Achievement

An ideal biosensor for monitoring of contaminants in a manufacturing process or in the environment needs to be sensitive, simple to use, and employ minimal sample processing. Systems requiring extensive sample extraction or highly skilled personnel will not gain widespread acceptance. NRL has developed biosensors for field use that are portable, easy to use, and require only that the sample be a relatively nonviscous liquid. NRL's biosensors use antibodies and other biomolecules to recognize biological threat agents and environmental hazards rapidly and at extremely low concentrations.

NRL's fiber-optic-based biosensors have been used to measure biological toxins in river water and clinical samples (blood, serum, plasma) or harmless bacteria released in field exercises and collected from the air. DNA-based assays, which can be used for verification of immunoassay screens, have also been developed. In addition, the biosensors have been used to detect drugs of abuse in urine and saliva and to monitor explosives in groundwater or soil.

The Analyte2000 was first developed at NRL for deployment during Operation Desert Storm. This device was the first biowarfare agent detector to demonstrate remote identification of aerosolized bacteria while mounted on an unmanned aerial vehicle.[99] It has since been transferred to commercial manufacture. Research International is marketing the RAPTOR fiber optic sensor and has signed agreements with Canon to supply sensors for food testing and with BAE Systems to provide devices for biological warfare agent detection. The flow immunosensor technology has been commercialized in an instrument designed for on-site lab-quality drug testing.

Impact

NRL's portable biosensors have demonstrated in the field how antibody recognition can be integrated with state-of-the-art optical components to recognize hazardous substances in complex samples. The sensors are sensitive, automated, straight-forward to use, and provide valuable on-site detection capabilities. The sensors are capable of detecting biological toxins in water, blood, serum, and plasma; detecting drugs of abuse in urine and saliva; and monitoring explosives in groundwater or soil.

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[99] "On Alert Against the Bio-Agents," *Jane's International Defense Review* (1 Nov 1998), p. 53.

Mesoscale Prediction Systems

Achievement

Two mesoscale prediction systems have been developed and transitioned to operations by NRL: the Navy Operational Regional Atmospheric Prediction System (NORAPS) and the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS).[100] NORAPS, implemented in 1982, became the first globally relocatable limited-area model of its kind, and in 1985, it became the first regional model in the world to use data assimilation. NORAPS supported naval operations in Operation Desert Shield, Operation Desert Storm, Operation Tandem Thrust, Bosnia, Somalia, and Haiti.

COAMPS replaced NORAPS as the Navy operational mesoscale model in 1998. COAMPS allows for more accurate forecasts over areas that exhibit steep topographic features and strong convection, predicts tropical cyclone track and structure, predicts the distribution of aerosols, and explicitly predicts water and ice clouds, as well as rain and snow. It has been used to supply forensic re-analyses of the atmospheric conditions (wind, temperature, moisture, and pressure) during Operation Desert Storm in support of the Presidential Advisory Committee's investigation into Gulf War Illness.[101] For example, it produced estimates of where chemicals, accidentally released from the demolition of a large ammunition storage site near Khamisiyah, Iraq, may have been transported. Independent expert panels praised NRL's efforts for providing the most accurate assessment of the mesoscale meteorology during that time.[102]

COAMPS is supporting operations in Afghanistan and Iraq by providing high-resolution wind simulation data to help evaluate the effects of wind variability on munitions targeting and the probable atmospheric effects upon aircraft detection and ranging systems. Measurements from instruments aboard earth-observing satellites, combined with dust modeling research, were used to provide real-time assessments of atmospheric dust conditions and dust storm prediction. In fact, a database of dust source regions in Southwest and East Asian deserts was developed based on field studies, satellite remote sensing, and topography. It allows high-resolution dust storm forecasts for Iraq, Iran, and Afghanistan. COAMPS was also used to produce local forecasts aboard an aircraft carrier, a world-first accomplishment.

Impact

NRL's NORAPS and COAMPS are mesoscale data assimilation systems used for generating high-resolution numerical analyses and short-term (0 to 48 hour) predictions of the atmosphere for limited areas of the Earth. Weather maps produced from these systems are distributed to operational DoD commands around the world to support mission planning, ship and aircraft operations, and hazardous weather avoidance. COAMPS has also been requested and is routinely used by other organizations. For example, DoE's Lawrence Livermore National Laboratory uses the model to assist in providing transport and dispersion forecasts of hazardous material releases. The Weather Channel also uses COAMPS data.

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[100] COAMPS and COAMPS-OS (On Scene) are trademarks of the Naval Research Laboratory.

[101] Chang, S.W., et al., "A Meteorological Re-Analysis for the Study of Gulf War Illness," NRL/MR/534--98-7233, January 1998.

[102] "Comments by Peer Review Panel on Khamisiyah Modeling Report and Presentations, 4-5 November 1997," (11 Dec 1997).

Nuclear Quadrupole Resonance for Detection of Explosives and Narcotics

Achievement

NRL invented technology for the detection of explosives and narcotics by the method of nuclear quadrupole resonance (NQR). NQR is a radio frequency (RF) spectroscopic technique, related to nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI). However, no large magnet is required in NQR. The specimen is irradiated with RF energy at specific frequencies, and the size of the return signal indicates the presence or absence of known explosives and narcotics.

NRL scientists pioneered the practical use of NQR for explosives and narcotics detection by successfully addressing the technical issues required to take NQR out of the laboratory and into the field. One key technical breakthrough allows NQR inspection by low-power RF pulses, rather than the extremely high power required in earlier approaches. A second is a customized RF inspection coil specifically applicable to the screening of personnel, so that minimal RF energy is deposited. A third approach minimizes some of the technical problems of acoustic ringing in metal contents of baggage and also reduces the temperature variation of the NQR signal.

NRL work on NQR was originally funded by the Federal Aviation Administration (FAA) and the DoD (Defense Advanced Research Projects Agency (DARPA) and the Office of Special Technologies), to advance U.S. capabilities in antiterrorism and antidrug efforts. Explosives detection systems for package and baggage scanning in airports and other fixed sites have been built by Quantum Magnetics under NRL license. Several package scanners have been sold to the FAA and to the DoD (for mail scanning). More recently, NRL has applied this research to land mine detection, which is both a military and humanitarian requirement.

Impact

This technology provides a major advancement in the state of the art for explosives and narcotics detection. In 1997, the White House Commission on Aviation Safety and Security recommended that NQR systems be purchased and deployed to enhance security at U.S. airports. NQR is in a preliminary testing stage for land mine detection.

Primary Reference Documents

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Surface Acoustic Wave Chemical Sensors

Achievement

NRL scientists pioneered the use of surface acoustic wave (SAW) technology to detect chemical vapors. The NRL R&D efforts, dating back to 1981, were supported in the developmental stages by the U.S. Army and Air Force, and will become a fielded technology at the point when the DoD's Joint Chemical Agent Detector (JCAD) goes into production.

JCAD is a handheld device that provides users with the capability to detect, identify, quantify, and localize automatically the presence of chemical warfare agent (CWA) vapors by agent class (nerve, blister, etc.). JCAD also will provide field commanders information on the type, level, and extent of CWA contamination and total CWA exposure received.

NRL's SAW research and development efforts have focused on developing chemically selective coatings for the device to have chemical selectivity and pattern recognition methods for CWA identification. In the early 1990s, NRL developed the first instrument that included a 4-SAW sensor array (for reduction of false alarms) and a preconcentrator (for increased sensitivity). Pattern recognition algorithms were also employed to interpret the results. From 1993 to 1995, the SAW sensors were field tested in Korea, and in the late 1990s, an NRL SAW device was tested in an unmanned aerial vehicle.

Impact

SAW chemical sensors, like those implemented in JCAD, are a major capability for military and homeland defense detection of chemical warfare agents. Advanced prototype units of JCAD were deployed in Operation Iraqi Freedom, and at present BAE is selling a commercial model of the JCAD.

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Tactical Receive Equipment

Achievement

In the area of tactical receive equipment, NRL developed two major items: the Multi-Mission Advanced Tactical Terminal (MATT) and the Improved Data Modem (IDM).

MATT: The MATT is a satellite communications, ultra-high-frequency, four-channel radio terminal, with a multi-user format output capability in an 8 x 8 x 19-inch frame. This self-contained unit is capable of simultaneously receiving, decrypting, and processing intelligence reports. The U.S. Special Operations Command (SOCOM) selected NRL to develop the unit. NRL successfully met SOCOM design requirements and delivered the first qualified units in 24 months. The successful evaluation of the MATT led to the milestone decision for full-rate production and transfer of the technology to industry as the Airborne Joint Tactical Terminal (JTT).

IDM: In 1990, the Air Force chose NRL to lead a multiservice, multidisciplinary team in developing a high-speed digital data modem for use by F-16 aircraft to pass targeting data and situational awareness updates rapidly. NRL's successful record in space and satellite systems development made it uniquely qualified for the task of maximizing performance, reliability, and quality, while minimizing size, weight, and power. Just nine months later, NRL had developed, produced, and delivered the first five units for aircraft integration. Throughout the process, NRL incorporated design features to enhance reliability and simplify automated assembly and production. In 1993, the technology transfer process was completed, three months ahead of schedule and under budget, with the award of an Air Force contract to a small business using the drawing package delivered by NRL. The Air Force considers the IDM program to be one of the finest examples of acquisition streamlining.

Impact

MATT filled a need for a miniaturized multifunction radio and processor that provides near-real-time national intelligence data to field commanders and tactical fighters. In addition, MATT provides the ability to combine both intelligence and theater data in the selection of targets. The IDM program established the first digital data link capability between fighter aircraft and between fighter aircraft and ground units. The IDM provides pilots the ability to do in seconds (or less) what used to take several minutes by voice radio, thus minimizing exposure to enemy jamming and/or transmission interception. It is used on Air Force F-16s[103] and Navy carrier-based EA-6Bs serving in the Persian Gulf. It is a key component in all Army aviation platforms and numerous Air Force programs.

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AN/ALE-50 Towed Countermeasures

Achievement

NRL's earlier development of monopulse radar provided a ten-fold improvement in angular accuracy for long-range tracking by fire and missile control radars.[104] By the 1970s, however, adversaries had applied monopulse capabilities to their surface-to-air missiles. This created a distinct threat to American aircraft. NRL responded to this threat by development of the Airborne Active Expendable Decoy (AAED), which was an electronic device designed to counter modern radar-guided antiaircraft threats. Laboratory researchers initially explored the development of both towed countermeasures and decoys attached to aircraft launched missiles for threat deflection. Eventually, towed concepts proved more practicable, and the towed version of the AAED, the AN/ALE-50, was the first towed decoy to be used as an in-flight countermeasure.

The towed decoy concept differs from the traditional goals of electronic warfare where antiaircraft missiles are denied the information needed to launch and intercept. Advances in monopulse radars and processing have made this an increasingly hard task. Instead, the towed decoy's effectiveness lies in looking more like an aircraft than the aircraft itself, pulling the threat to itself instead of pushing it away, as in the case for onboard systems.

During the joint Navy/Air Force Multi-Service Decoy Program, flight-worthy devices were tested and proved to be extremely effective. Over the years, the AN/ALE-50 has surpassed expectations at every stage of its development. The end result of this work has been an increased capability for the U.S. military.

Impact

NRL's AN/ALE-50 has made billions of dollars worth of advanced antiaircraft threats in the hands of the U.S.'s opponents less effective. It has had a dramatic impact on the way U.S. aircraft fly and fight. Until the AN/ALE-50, aircrews were forced to fly low altitude, "nap-of-the-earth" flight paths to avoid the radar-guided threat, which, in turn, forced them into the envelope of shoulder-fired missiles and antiaircraft artillery. In fact, this decoy protects combat aircraft so well that it has earned the nickname "Little Buddy" from our pilots.[105] In the Kosovo campaign alone, 1,479 were used and the system was credited with saving several aircraft.[106]

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[105] "Order for ALE-50 Doubles After Success in Kosovo," *Aviation Week & Space Technology*, 15 November 1999.

[106] http://www.lexingtoninstitute.org/defense/ewarfareqdr.htm, and Benjamin Lambeth, *Aerospace Power Journal*, Summer 2002, p. 21.

Low Observables Detection Radar

Achievement

In response to the USS *Stark* incident and to the increased deployment of U.S. forces in dangerous littoral and other heavy clutter environments, NRL scientists developed and tested shipboard radars that can detect and track low-radar cross section air and surface targets that pose potential threats to naval assets.

Sea Skimmer Detection Radar. NRL developed and tested an advanced development model shipboard radar that detects and tracks sea-skimming missiles near the horizon in difficult littoral environments, with extremely low false alarm rates. The radar operates simultaneously in both surface and air modes, with the air mode providing an unprecedented clutter rejection level that is orders of magnitude better than previous technology. The surface mode is able to track small boats and helicopters in heavy sea clutter. The new technology was obtained at low cost and light weight. The radar, now named the AN/SPQ-9B Anti-Ship Missile Defense radar, was transitioned to Northrop Grumman for production.

Low Observable Detection and Tracking. NRL developed operational means for applying the NRL-developed, large power SENRAD radar to the littoral environment. Operating at full sensitivity, this large aperture radar is able to detect and track small targets. Laboratory researchers raised the radar's pulse repetition frequency and developed new innovative processing techniques to enable the radar to reject signals from stationary clutter while ignoring clutter from slow moving nuisance targets, consisting primarily of birds. The radar was then able to concentrate on small, high-speed targets of interest, at a small false tracking rate.

Impact

The AN/SPQ-9B radar was approved for full-rate production in February 2004. It is the only Fleet radar that has been shown to detect and track sea-skimming missiles near the horizon in difficult littoral environments, while maintaining very low false-track rates. It is an important addition to naval armament in confined sea environments such as the Red Sea and Persian Gulf. NRL's low observable detection technology has been able to provide the AN/SPS-49 radar the ability to detect and track very small high-speed targets through heavy land, sea, rain and ducted clutter, as well as when large numbers of nuisance objects, such as birds, are present. It provides the Navy the capability to detect and defend itself from attacks from small high-speed vessels in the littoral environment. The AN/SPQ-9B radar is installed on the CVN-68, CVN-76, CV-67, and LPD-17, and is under consideration for the CG-47, DD51, and LCS ship classes.

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First Software Defined Tactical Radio

Achievement

In 1989 the Department of Defense recognized the need to address the serious tactical communication problems that were occurring on the battlefield. Existing tactical radios lacked interoperability and could not be easily integrated onto military platforms. Comprehensive communications across the battlefield required the simultaneous use of many different radios. In response, military R&D efforts were initiated to develop a radio that could be software adapted to supporting tactical communications over multiple bands and modes.

In 1994, the U.S. Army contracted NRL to develop an airborne Tactical Operational Center (TOC) that was to be housed in a UH-60 Army Blackhawk helicopter. The TOC would need to support 37 heritage radios, an impossible housing and power demand for a single helicopter. To meet the Army's needs, NRL developed the Joint Combat Information Terminal (JCIT), an eight-channel software radio designed to meet the environmental, volume, and power constraints of the UH-60. The JCIT, through the mediation of software, took the place of the 37 heritage radios, demanding as a consequence only a fraction of the latter's size, power, and weight.

Impact

The JCIT has been installed and operated on a number of military platforms. As the first military software radio to be successfully field-tested, the JCIT has contributed significantly to the proof-of-concept that the use of software-definable radios could be the basis for solving tactical communications problems. Many of the processes and implementation mechanisms developed for the JCIT have been adopted by the later, more comprehensive Joint Tactical Radio System (JTRS). JTRS is mandated as the basis for acquisition of all future tactical communication systems. Additionally, the principles established in implementing JCIT have also been applied to civilian communications problems, most particularly those relating to homeland security.

Primary Reference Documents

- SSD-S-AA001 System Specification for Army Airborne Command and Control System (A2C2S)
- SSD-S-AA800 Prime Item Development Specification for the JCIT

CT-Analyst

Achievement

The CT-Analyst system (Contaminant Transport System) is the first operational, instantaneous emergency assessment system for airborne contaminants and WMD (Weapons of Mass Destruction) threats in cities.

CT-Analyst takes full account of the effect of buildings on the airflow and is both faster and more accurate than all other existing or proposed systems. It automatically combines data from sensors and verbal reports to plot optimal evacuation routes through use of an entirely new fluid dynamics solution methodology called dispersion nomographs. This new approach uses detailed 3D, high-resolution fluid simulations to generate a complete database for the wind flow over a realistic city, with all buildings and trees included. The database is compressed into 18 tables, or dispersion nomographs, for each of 18 wind directions over the city. The resulting information helps plan effective defense strategies against accidental and intentional contaminant releases.

Impact

CT-Analyst is already in use by federal emergency managers, police and fire officials in Washington, D.C. and Chicago, Illinois, for everyday as well as crisis use. CT-Analyst was used by the Naval Central Command during Operation Iraqi Freedom for the protection of U.S. forces and strike planning consideration. It has been selected by the Missile Defense Agency for urban dispersion and consequence management and is being implemented for force and base protection, as well as mobile deployment in conflict situations.

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Mountain Wave Forecast

Achievement

Mountain waves are among the most hazardous conditions that aircraft encounter. They are the result of air rising up the windward side of a mountain and then, under certain atmospheric conditions, descending on the leeward side. This results in the formation of a series of standing waves downwind from the mountain that may extend over considerable areas and form a potential flight hazard.[107]

Mountain wave turbulence is the major global source of severe turbulence for high-altitude long-endurance DoD aircraft such as the U-2s and Global Hawk unmanned aerial vehicles. To reach their 60,000 to 70,000 feet cruise altitudes, such aircraft must eliminate weight and maximize lift, sacrificing some of the heavy structural rigidity of conventional aircraft. This makes them vulnerable to any severe turbulence they may encounter at altitude. They also have enormous geographical range, and thus require global forecasts of atmospheric conditions for safe flight planning.

In response to these challenges, NRL scientists developed the Mountain Wave Forecast Model (MWFM), which is the only meteorological model capable of globally forecasting mountain wave activity and wave-induced turbulence in the Earth's atmosphere from near the surface to beyond 100,000 feet. MWFM is also a valuable tool for fundamental atmospheric research. It has been used to direct flights with NASA / European Union aircraft and balloons for studying the physics of polar stratospheric clouds. MWFM provides hemispheric hindcasts of mountain wave effects for global chemical transport models related to the study of the seasonal impact of PSCs on winter ozone loss in the Arctic, and it has provided modeling support for the first observations of mountain waves from satellite platforms.

Impact

MWFM has had an impact on turbulence forecasting for military and civilian aircraft. It was used to predict flight conditions for allied aircraft during operations Southern Watch, Enduring Freedom, and Iraqi Freedom. It was adapted to run hindcasts of stratospheric mountain wave turbulence over Afghanistan from 1994 to 2001, in order to generate a multiyear climatology of anticipated turbulence levels and geographical distributions, in response to requests from the Air Force Combat Climatology Center. NASA also routinely requests MWFM turbulence forecasts for flight planning during airborne science campaigns with their instrumented DC-8 and high-altitude ER-2 research aircraft.

Primary Reference Documents

- Bacmeister, J.T., P.A. Newman, B.L. Gary, and K.R. Chan, "An Algorithm for Forecasting Mountain Wave Related Turbulence in the Stratosphere," *Weather Forecasting*, Vol. 9, pp. 241-253 (1994).
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Low Solar Absorbance Ship Paint

Achievement

NRL developed Low Solar Absorbance (LSA) paint in order to reduce solar heating on Navy ships. The paint was tested in 1995, when it was applied to the USS *Dextrous* (MCM 13), and it produced a significant reduction in surface temperatures during summertime operations in the Gulf of Mexico. Testing demonstrated that LSA not only reduced ship surface temperatures and the load on air conditioning systems, but also decreased the ship's infrared (IR) signature.

The USS *Dextrous* has since been deployed to the Persian Gulf where the paint's solar reflective properties reduce heat buildup, increase crew comfort, and decrease the ship's IR signature. LCA paint has been transitioned into the Fleet, and now all Navy ships are painted with the NRL-designed paint.

Impact

LSA paint has reduced solar heating on Navy ships, leading to lower air conditioning and maintenance costs and greater crew comfort. The paint has reduced the susceptibility of all coated Navy ships to hostile IR sensors and to IR-guided munitions. The per gallon cost of the LSA paint is virtually identical to the Standard Haze Grey paint it replaced, resulting in a cost-effective infrared stealth technology for the Navy. It is now the standard paint applied to all U.S. Navy vessels.

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InfraLynx

Achievement

Prior to 2001, NRL engineers designed an interoperable communication infrastructure (InfraLynx) to provide assured communication capabilities to military and civilian authorities for use in areas where the local infrastructure is destroyed or completely saturated. Three days after the September 11 terrorist attacks on the Pentagon and the World Trade Center, NRL responded by integrating the InfraLynx architecture into two Highly Mobile Multi Wheeled Vehicles to provide a satellite-enabled complex of multiple telephone lines, high-speed network access, and private cellular and radio interoperability. The resulting capability would allow First Responders to communicate when the local infrastructure had been destroyed, as was the case with the World Trade Center in New York City, or when the infrastructure was completely saturated, as was the case at the Pentagon.

The Federal Office of Domestic Preparedness quickly adopted InfraLynx as the primary element of the Pre-positioned Equipment Program and began an aggressive program of field exercise and training drills to make agencies around the country aware of this technology. This began with a deployment to the 2002 Winter Olympics in Salt Lake City and has continued with several national security events, Weapons of Mass Destruction (WMD) training exercises, and Super Bowl XXXVII.

Impact

InfraLynx has set the U.S. standard for assured communications and radio interoperability and has filled a serious emergency communications gap that existed among federal, state, and local agencies prior to the September 11 terror attacks. It was deployed by the Office of Domestic Preparedness for contingency communication support during the 2002 Winter Olympics in Salt Lake City and during Super Bowl XXXVII. InfraLynx has been on more than 16 deployments since 9/11, supporting counter-terrorism training, WMD preparedness drills, communications interoperability evaluation and awareness programs, and Hurricane Katrina relief efforts.

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SHARP Reconnaissance System

Achievement

The F/A-18 SHAred Reconnaissance Pod (SHARP) is a digital reconnaissance system developed by NRL scientists to replace the aging film-based F-14 Tactical Airborne Reconnaissance Pod System (TARPS). SHARP provides high-resolution visible and infrared digital imagery from medium and high altitude cameras.

The system is controlled by the NRL-developed Reconnaissance Management System and ground station technology, which allows for real-time compression, on-board storage and manipulation, and off-board dissemination of the imagery. Real-time imagery is delivered to ground and sea-based forces through radio and wideband digital data links.

SHARP technology includes day / night imaging, in-cockpit image review and exploitation, precision geo-coordinate determination for targeting applications, manual or automatic mission execution, real-time dissemination of imagery products to ground stations, and standardized hardware interfaces. The multi-functional SHARP technology is adaptable to manned or unmanned platforms.

The SHARP reconnaissance system and the associated ground station technology have been successfully transitioned to the Navy for full-rate production. SHARP and related efforts can also be applied to border monitoring.

Impact

The first production systems were installed on F/A-18 aircraft and the USS *Nimitz* and were deployed in Operation Iraqi Freedom (OIF). In addition, SHARP-based reconnaissance technology was used in OIF with an F-14 squadron on the USS *Truman*. Front-line Coalition Forces received targeting imagery directly from this system. The timeliness of this imagery, as opposed to the three-to-nine day norm associated with predecessor imaging systems, was critical to advancing U.S. objectives and saved Coalition lives. The SHARP program development has outperformed "all previous joint service efforts to rapidly develop, prototype, and field affordable manned and unmanned imaging systems."[108]

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Dragon Eye

Achievement

NRL scientists, in collaboration with the Marine Corps Warfighting Laboratory, developed an affordable and expendable airborne sensor platform, Dragon Eye, to provide small unit reconnaissance, battle damage assessment, and threat detection capabilities to the U.S. Marine Corps.

Dragon Eye consists of a man-portable, 5.5 lb., hand-launched air vehicle and a miniature Ground Control Station to provide command and control and to receive the aircraft's video and GPS position. The vehicle flight characteristics permit operational use in adverse weather conditions, and the autonomous flight capability allows one-person operation. Operational flight endurance is 45 minutes, at an airspeed of 35 knots, with a range of 5 miles, by using an electric propulsion system with primary lithium batteries. Interchangeable modular component payloads include daylight, low-light, and infrared imaging systems.

Impact

Dragon Eye was successfully transitioned to the Marine Corps Systems Command (MCSC), and pre-production units were deployed with the 1st Marine Expeditionary Force in Iraq during Operation Iraqi Freedom (OIF). These units provided critical intelligence to American forces in the field. A post-OIF review from the 1st Marine Division noted that on-site intelligence delivered by Dragon Eye proved to be the conspicuous bright spot in overall OIF intelligence gathering.[109] MCSC awarded a Dragon Eye production contract to AeroVironment, Inc., in December of 2003.

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Secure Voice Technology

Achievement

In the 1990s, the Department of Defense introduced a new narrowband voice-processing algorithm, called the Mixed-Excitation Linear Predictor (MELP), for supporting tactical communications. NRL scientists in the 1970s had specified and developed the predecessor LPC voice-processing algorithm for use with the DoD's Advanced Narrowband Digital Voice Terminal (ANDVT), DoD's most widely used operational tactical terminal. Because of this work, the DoD's Voice Processor Consortium asked the Laboratory to investigate means of converting MELP voice data into the ANDVT voice data (and vice versa) so that these two DoD tactical secure phones can interoperate directly. Without the use of conversion software, 40,000 ANDVTs that are supporting tactical voice communication for users in DoD and special government agencies would have been made redundant and there would have been a potentially long transition period.

In response to the DoD request, NRL scientists took only six weeks to develop a voice communications processing algorithm for the translation process. The NRL solution resolved the conversion problem, and the resulting algorithm has been widely disseminated both within the DoD and within NATO forces.

NRL has also developed an enhanced version of the LPC algorithm, which was incorporated into the 2400 b/s version of the third-generation Secure Terminal Unit (STU-III) telephone. NRL's Line Spectrum Pair (LSP) technology was incorporated into the 4800 b/s version of the STU-III. The Navy has deployed over 60,000 STU-IIIs incorporating the 2400 b/s algorithm, with 35,000 of these also having the 4800 b/s algorithm.[110]

Impact

A range of NRL's voice communications processing algorithms and technologies have been widely disseminated and used within the DoD and the armed forces of allied countries. Almost all low-data-rate DoD or COTS vocoders now use the NRL-developed LSP technology. The NRL narrowband voice translation system provides direct interoperability between old and new speech parameters, allowing the new and the legacy ANDVT phones to work together. The result of this development was that 40,000 legacy phones did not have to be retired prematurely, and there was no long transition period between the new and old systems. The continued use of these legacy units resulted in a one-time cost savings of nearly $460 million for the DoD.[111]

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[111] The following numbers are from SPAWAR's ANDVT Program Manager and "Naval Advanced Secure Voice Architecture," SPAWAR Systems Center, (Version 0.1) 26 February 2004, p. AV-68. Total deployment was approximately 40,000 units (29,512 ANDVTs at $28,744/unit; 9,363 KY-99As at $6,207/unit; 342 KY-100s at $12,861/unit; and 700 Tacterm ANDVT Shore Systems at $10,000/unit), of which 26,917 units went to the Navy, at a total procurement cost of $917,807,531. Since 50% of the ANDVT life cycles are over, the DoD and Navy saved 50% of the total paid by avoiding replacement costs due to block retirement.

Pulsed X-ray Radiography

Achievement

The rod pinch is a cylindrical, pinched, electron-beam diode that can be used as a bright x-ray source. The diode is connected to a pulsed power generator, producing a high current pulse of electrons that converge onto the tip of the rod, thus producing an extremely intense burst of x-rays. The rod pinch is particularly well suited for x-ray imaging (radiography) applications requiring high x-ray dose, moderately deep penetration, resolution of small feature sizes, and sub-microsecond time resolution.

The rod-pinch radiography source was invented by NRL in the late 1970s but was largely ignored until the last few years. Since 2000, NRL has made significant progress in refining the original vacuum rod pinch, producing a combination of small source size and high radiation dose that is unmatched by more conventional sources. A second-generation version, the plasma-filled rod pinch, produces an extremely intense x-ray source with parameters thought to be impossible with conventional techniques.

The Stockpile Stewardship program of the Department of Energy (DoE) has been the primary user for the rod pinch. The program is administered by the DoE's National Nuclear Security Administration, which has the mission to validate and sustain the operational capability of the nuclear stockpile and to improve nuclear weapons physics understanding. In particular, the program requires radiography sources to diagnose the performance of nuclear weapons components at extreme densities and pressures. NRL's vacuum rod pinch has been highly acclaimed as the radiography source of choice for many of these applications, producing "outstanding results."[112]

Impact

NRL's device plays a vital role in the nation's nuclear Stockpile Stewardship program. It was the x-ray source for the Cygnus generator used in a recent experiment at the Nevada Test Site that demonstrated a major leap in capability, leading the Los Alamos National Laboratory to state, "Many innovations have combined to lead to this leap in performance, but perhaps the most important has been the effective realization of the rod-pinch diode originally developed at NRL."[113] NRL scientists received a DOE Nuclear Weapons Program Award of Excellence in 2003 in recognition of this work.

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[112] Final Report of the 6.1 External Review Panel — Chaired by C.L. Olson, Sandia National Laboratories (July 16, 2004), p. 6.

[113] Fulton, R.D., Wilke, M.D., King, N.S.P., "Dynamic Materials Studies in Subcritical Experiments: Rocco, Mario, Vito, and Armando," Materials Studies Research Highlights (Physics Division: Los Alamos National Laboratory), p. 26, found at http://www.lanl.gov/orgs/p/highlights.shtml.

Project Silent Guardian

Achievement

Concerned about military and civilian health during special events in the National Capital Region (NCR), the Office of the Secretary of Defense (OSD) requested that the Air Force Surgeon General's (AF/SG) office implement biosurveillance technology developed by NRL scientists for the U.S. Air Force's Epidemic Outbreak Surveillance (EOS) project.

The EOS biosurveillance technology, Re-sequencing Pathogen Microarrays, is a system that can identify large numbers (20 to 100 depending on the chip) of pathogens simultaneously, including bio-threat agents and emerging diseases such as avian flu. The approach was previously demonstrated successfully for adenovirus and influenza detection in a limited patient population. The challenge OSD presented to the NRL was to take the complex technology from the laboratory to production scale and implement the approach as a demonstration project from 1 December 2004 to 31 March 2005.

NRL, along with critical help from the AF/SG office, the Joint Program Executive Office for Chemical and Biological Defense, and private industry, moved from routine laboratory research to Full Operational Capability in less than six weeks. The NRL EOS Team trained incoming Air Force personnel, developed solutions for problems that arose in analyzing large numbers of samples, and set up two complete production lines of equipment and reagents.

Recent results have demonstrated clinical agreement for strain level identification of influenza and other pathogens at better than 90%. Avian flu (H5N1) has been identified successfully to the strain level. Further development is aimed at automation, portability, and simplified use.

Impact

NRL successfully responded to high-level concerns for military and civilian health during special events held in the Washington, D.C. area during the 2005 Presidential Inauguration. The combined Silent Guardian team, composed of NRL scientists, Navy reservists, and U.S. Air Force staff, successfully made the first demonstration of a capability for rapidly (i.e., less than 24 hours) obtaining data for a broad range of pathogens in clinical specimens collected from the general population.[114] In addition, the team demonstrated accurate detection of samples spiked with inactivated bio-threat agents in blind trials, identified numerous cases of influenza in patient samples collected from military treatment facilities within the NCR, and clearly demonstrated the utility of the Epidemic Outbreak Surveillance protocol for medical diagnostics as well as surveillance.

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Tactical Microsatellite Experiment (TacSat-1)

Achievement

NRL and the DoD Office of Force Transformation (OFT) are developing a tactical microsatellite system with the goal of making rapidly deployable spacecraft and their capabilities available to support military operations anywhere on Earth. TacSat will provide selectable payloads tailored to a specific area or conflict. Payloads will be under direct control of the Joint Task Force commander, making space assets an organic part of the force.

TacSat-1 has several payloads that provide capabilities for cross-platform missions, specific emitter identification, and visible and infrared imaging. It will be launched aboard the SpaceX Falcon launch vehicle.

Impact

TacSat-1 will put space-based, rapidly deployable, mission-relevant capabilities into the hands of the Joint Task Force commander, anywhere on Earth. It will make space assets an organic part of tactical operations.

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Body Armor to Counter Improvised Explosive Devices

Achievement

Nearly two thirds of the wounds sustained by U.S. troops in Iraq and Afghanistan are to the extremities, with 6 percent of the wounded requiring amputations.[115] Medical personnel have reported that most extremity wounds are being caused by fragments about the size of a pencil eraser, typically from improvised explosive devices (IEDs).

At the request of the Chief of Naval Research, NRL conducted an eight-month rapid response program to develop strong and flexible body armor to protect the warfighter's arms and legs (intended to augment the standard Outer Tactical Vest) without compromising agility. The resulting body armor incorporates new ballistic materials and designs determined after exhaustive studies that balanced vulnerability to injury and amputation against factors such as weight, flexibility, comfort and appearance. The design principles for the armor were formulated from anatomical vulnerability studies, the blast threat, and injury statistics, which required interaction with medical personnel, ballistic testing experts, warfighters, and clothing designers. NRL's work was supported by the Army Research Laboratory, Oklahoma State University, and FS Technology.

The new technology transitioned from laboratory to combat use in only 17 months. Ten different combinations of ballistic materials were evaluated by ballistic testing before choosing the materials from which to build the armor. A set of five prototypes was produced in the first 30 days of the program to evaluate basic concepts. Twenty Phase II prototypes with an improved design were completed 90 days later. The design protects 85% of the surface areas of the arms and legs while being lightweight, flexible, and is compatible with weapons and other equipment. It is also cool enough to be worn in desert climate. The first units were fielded by Marines in Iraq in November 2005.

Impact

For the first time, U.S. Marines will be able to augment the standard equipment OTV (Outer Tactical Vest) with blast fragment protection for the arms and shoulders, legs and hips, and buttocks. It is expected that the frequency of amputation of extremities will be reduced by a significant factor. Recently, 5,000 units of the present QuadGard Phase IV Design were deployed to U.S. Marines in Iraq. Among the likely users of this body armor are convoy crews and vehicle occupants, sentries and checkpoint forces, security personnel, roadside patrols, explosive ordnance reconnaissance personnel, forward deployed medical personnel, and combat engineers.

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