

## BATTLE GROUP GRIDLOCK—AN UPDATE

Gridlocking is a process for aligning coordinate frames of units at sea to support the precise exchange of sensor data and, consequently, to support coordination of the actions of these units. An automatic process for gridlocking was demonstrated at sea by APL in 1983. Since then, there have been significant developments in the concept. The progress of gridlocking and future plans for its implementation are discussed.

### INTRODUCTION

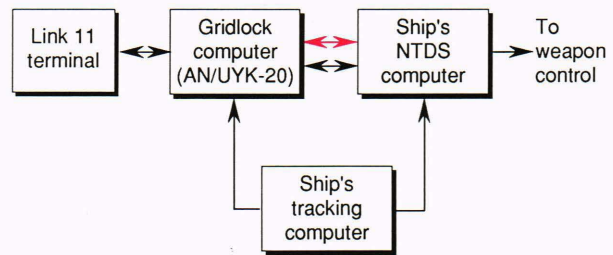
Gridlocking is the Navy term used to describe the process of aligning coordinate frames between units at sea. Such alignment is required to support both the accurate exchange of position reports and the synergistic tracking by battle group participants. These accurate exchanges are needed to sort (or correlate) targets that are actually held by two or more units (and thus are the same) from those that are not. Additional processing combines data from these units into one coherent track picture that is battle-group-wide. The picture allows the actions of units and assets in the battle group to be coordinated to ensure maximum effectiveness and the survivability of the battle group as a whole. Precision gridlock is clearly fundamental to the success of this effort.

A previous article<sup>1</sup> examined an approach to precision gridlock alignment that used comparisons of radar track pictures between two sites. At the time, the process had been successfully demonstrated only at land-based sites (Applied Physics Laboratory and the Naval Research Laboratory) after the fact (i.e., off-line). The results were promising, but more work was required before use in the fleet.

That approach to gridlocking has now been demonstrated successfully on both surface and airborne platforms in the fleet in real time, and several new features have been added since the original design. Each demonstration and feature was developed in a series of more or less independent steps. The following paragraphs present an overview of each step.

### GRIDLOCK DEMONSTRATION SYSTEM

The concept outlined<sup>1</sup> was implemented by APL in real time in a militarized minicomputer (AN/UJK-20) (Fig. 1). The system, called the Gridlock Demonstration System (GDS), was tested with both simulated and radar data at the Fleet Combat Direction System Support Activity (FCDSSA) in Dam Neck, Virginia, in 1983. It was then installed, along with a detection data converter (DDC) modification to the AN/SPS-48C radar, on the USS *John F. Kennedy* (CV-67) during a deployment to support a NATO fleet exercise off the coast of France.

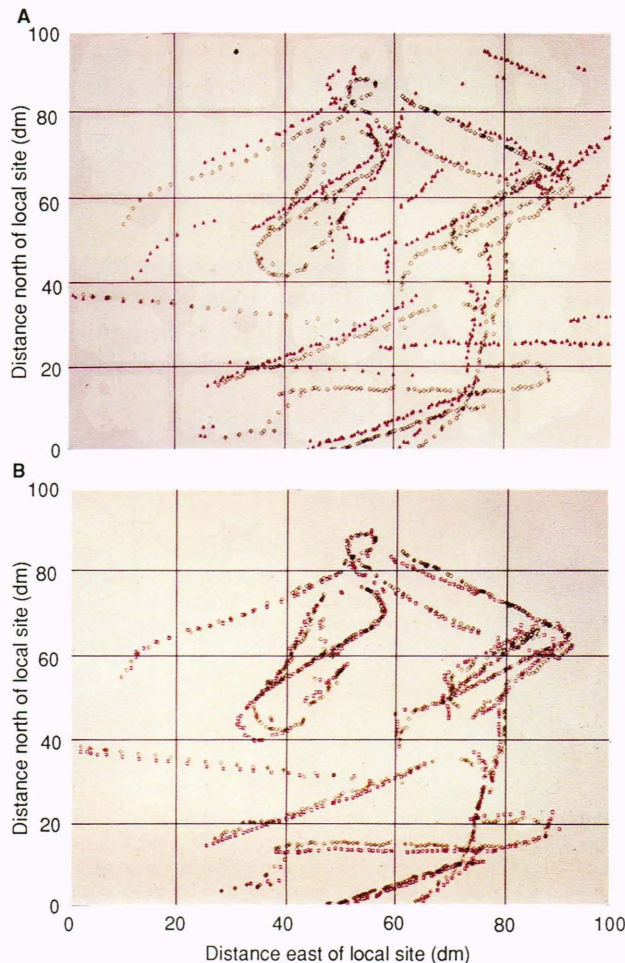


**Figure 1.** By inserting a minicomputer between the shipboard Naval Tactical Data System (NTDS) computer and the communications Link 11 terminal, both the gridlock error estimation and Link 11 data correction processes can be performed without modifying either system. To assure that all ownship track data are available to the gridlock computation (not all ownship data are transmitted over Link 11), however, a separate interface to the ship's tracking computer is required. The SGS/AC (Shipboard Gridlock System with Auto Correlation) added a new dedicated interface (red arrow) between the gridlock computer and the NTDS computers to integrate fully the gridlock function into the combat system. Over this interface, the combat system controlled the gridlock function; provided Link and track information (data link reference point, gridlock reference unit designator, track error estimates), navigational position, and local surface-track data to the gridlock computer; and received gridlock status, pads, and correlation information from the gridlock computer.

(The modification, which greatly improved the automatic radar tracking capabilities of the 3-D AN/SPS-48C radar, is needed to ensure the availability of high-quality tracks for use in the gridlock process.<sup>1</sup>) During the deployment, the GDS performed well, providing real-time precision track data alignment to the *Kennedy* throughout the exercise.

Figure 2 shows data samples collected over about 20 minutes during the deployment, indicating the gridlock alignment achieved in real time on the *Kennedy*. An additional benefit of this implementation, not necessarily associated with the gridlock process, is also illustrated. In particular, because of various conditions associated with Link 11 (the intraforce datalink), the relationship between the local and remote track databases may vary discontinuously. At least one such jump can be seen in Figure 2A. The implementation of the gridlocking func-





**Figure 2.** Demonstration of gridlock alignment achieved on the USS *John F. Kennedy* using the GDS in the summer of 1983. Red triangles are local radar (AN/SPS-48C with DDC) track reports and brown circles are remote (E-2C) Link 11 reports. The presented data cover a time interval of about 20 minutes. **A.** The raw unaligned reports. **B.** The GDS-corrected data. Only tracks actually held by both units are shown.

tions used in the GDS automatically compensates for such transients (Fig. 2B). (The misalignment of the looping track in the center of the display results from tracker lag differences in the two sensor systems used.)

The success of this effort has caused the Navy to request that the system be developed for fleet installation and that a rotating pool of GDS and DDC units be established for the forward deploying units. The Laboratory established the pool and continues to support the installation of these units in more than 60 ships. Interestingly, the first pool installation was the *Kennedy* battle group, deployed in 1983.

### SHIPBOARD GRIDLOCK SYSTEM

The first effort to put the GDS into production (primarily a concept demonstration system) was the Shipboard Gridlock System (SGS) for Aegis. The SGS is a GDS with an Aegis interface to acquire the local AN/SPY-1 track data (GDS interfaced to the AN/SPS-48C with DDC 3-D

air surveillance radar available on many non-Aegis ships). The system was built and tested at the Aegis Combat System Engineering Development Site in Moorestown, New Jersey, in 1984 and then deployed on all Aegis cruisers. Developments under way to upgrade these systems to have an autocorrelation capability are described in the next section.

### SHIPBOARD GRIDLOCK SYSTEM WITH AUTOCORRELATION

Several shortcomings were evident for both SGS and GDS and resulted principally from a lack of direct interaction with the ship's combat system. In particular, the system was controlled through a separate terminal that required the operator to enter data already available in the combat system. The SGS and GDS were readily aware of dual tracks (tracks held simultaneously by two or more units) between ownship and the gridlock reference unit (GRU),<sup>2</sup> but without an interface, they could not provide these data to the combat system. The SGS (or the GDS) needed a local ownship position to transmit the gridlock remote data to the combat system. But since this position was only available to the gridlock function via the (Link 11) interface with the combat system, the unit had to be Link 11-active for a position to be transmitted on the Link 11 and captured by the gridlock process. Although the SGS and GDS aligned the *air* track pictures with high precision, the performance of the SGS and GDS was frequently evaluated using the *surface* track pictures. Since the surface tracks frequently came from sensors different from the air tracks, the gridlock alignment achieved was not always obvious.

To solve these problems, APL, FCDSSA/Dam Neck, and FCDSSA /San Diego jointly established an interface (Fig. 1 and Ref. 3) between the combat system and the gridlock function. Specifically, APL extended the gridlocking capability to include an automatic local-to-remote track correlation function, which was a direct outgrowth of the original automatic correlation routines used for the gridlock process. These routines were applied to all tracks, not just those from the GRU (as required for the gridlock function). The new interface was designed to provide local (manual or automatic) surface tracks for a separate surface gridlock.<sup>4</sup> Local ownship navigational position, data link reference point (DLRP), position uncertainty numbers, etc., required to operate the Link and to support a Link silent mode, were all provided automatically. These systems (one for the aircraft carrier and one for the non-Aegis cruisers), called the Shipboard Gridlock System with Auto Correlation (SGS/AC), were tested at FCDSSA/Dam Neck in 1985 and deployed in the USS *Nimitz* (CVN-68) battle group during a 1985 fleet exercise off the coast of Puerto Rico.

After those successful installations, FCDSSA /San Diego declared the carrier vessel programs operational, and SGS/AC was deployed with the *Nimitz* and, eventually, with all carriers. The cruiser program was returned to FCDSSA/Dam Neck for program acceptance testing and was deployed in 1986 on various cruisers, as the equipment became available. The system is currently deployed



on 24 ships in the fleet and deployment is planned on all Naval Tactical Data System and Aegis combatants.

## AIRBORNE GRIDLOCK SYSTEM

All gridlocking systems discussed thus far have been installed on surface units. Because the Navy also has airborne surveillance assets, principally the E-2C, the SGS/GDS computer program was reprogrammed into a smaller (9-lb) air-transportable computer that could be interfaced with the E-2C airborne tactical data system to provide the same capability for these units as for the surface units. The reprogramming was done in 1985, and the resultant Airborne Gridlock System was tested at the FCDSSA/San Diego facilities before it was installed on the E-2C aircraft aboard the USS *Carl Vinson* (CVN-70). Gridlocking was again demonstrated successfully.

## NEW THREAT UPGRADE OF THE SGS/AC

The Navy is refitting older surface units with a new combat system called New Threat Upgrade (NTU), which includes improved sensors [(AN/SPS-48E and AN/SPS-49(V5)), new sensor tracking (AN/SYS-2), and a new combat system, the Advanced Combat Direction System (ACDS) Block 0. From a gridlocking (i.e., SGS/AC) point of view, the 3-D sensor tracks are essentially the same as those used with the older AN/SPS-48C/DDC system. For the first time, however, NTU provides fully automatic tracking of 2-D (AN/SPS-49) air tracks. The SGS/AC (NTU) provides the additional processing to handle gridlocking and autocorrelation of local 2-D tracks (only to a remote 3-D GRU), as well as the standard 3-D capability previously available with SGS/AC. Transitions to and from 2-D or 3-D gridlocking are made automatically, without operator intervention, as required by the data available.

The system has been implemented and tested at FCDSSA/Dam Neck and was successfully tested on the USS *Scott* (DDG-995) during August 1989; it is awaiting full deployment with NTU units.

## OTHER CONCEPTS

Other projects under way include the following:

1. Sparse gridlocking. This is an extension of the current concept to very low mutual track numbers. The concept has been worked out theoretically, but because of its large memory requirements (to save track histories), it has not yet been implemented.

2. Geodetic gridlocking. All concepts described so far are relative in nature; that is, alignment to an arbitrarily selected unit, called a GRU, is provided. Any error in its coordinate frame is propagated throughout the gridlock-aligned Link flow. Several concepts for providing geodetic registration have been proposed<sup>5</sup> but have not been implemented, because an additional Link 11 message is needed to support the process.

3. Joint Tactical Information Data System gridlocking. The Joint Tactical Information Data System (JTIDS) is a new datalink planned to complement and eventually replace Link 11, which is currently in the fleet. When JTIDS was originally proposed, gridlocking was not part

of the JTIDS design. Extensive analysis and discussions have indicated the need for a gridlocking function, and an SGS/AC-like function is now the leading concept.

4. Advanced Combat Direction System Block 1. The ACDS Block 1 is the next-generation combat system for the fleet and is scheduled for introduction in the mid-1990s. This system, interfacing with the JTIDS, developed a new gridlocking concept that extended the original concept. Design and implementation considerations, however, appear to be moving the system back to the current SGS/AC concepts embedded in the combat system.

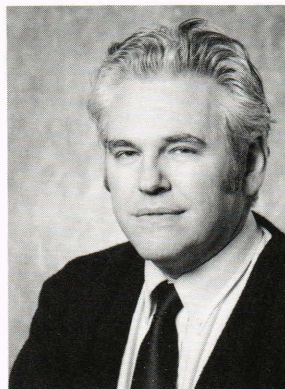
## CONCLUSION

The gridlocking concepts proposed 10 years ago appear to be soundly entrenched in the fleet today. Efforts are under way to move the gridlocking function into more capable (micro) computers, allowing the introduction of previously developed but unimplemented capabilities (sparse, geodetic), as well as supporting expanded track capabilities proposed for future combat systems. Finally, gridlocking schemes never before considered are being developed and tested, and may be deployed in the next decade.

## REFERENCES

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- <sup>2</sup>Bath, W. G., *Gridlock Analysis Report, Volume III: Automatic Correlation of Radar Track Data from Physically Separated Platforms in the Presence of Navigation Errors and Sensor Misalignments*, JHU/APL FS-82-023 (Jul 1982).
- <sup>3</sup>Lee, E. P., *Gridlock Demonstration System with Automatic Local to Remote Track Correlation Capability, Interface Design, Specification*, JHU/APL FS-84-183 (Jul 1983).
- <sup>4</sup>Miller, J. T., *Surface Gridlocking Concept*, JHU/APL F3D-2-1044 (1984).
- <sup>5</sup>Miller, J. T., and David, E. W. G., "The Role of Navigation in the Precision Registration of Sensor Data at Sea," *J. Inst. Nav.* 30, 123-134 (1983).

## THE AUTHORS



JAMES T. MILLER, Jr., is a section supervisor in the Anti-Air Warfare Systems Engineering Group in APL's Fleet Systems Department. He received a B.S. degree in physics in 1965 and a Ph.D. degree in physics in 1970, both from Pennsylvania State University. Employed at APL in 1972, Dr. Miller was responsible for development of the initial Gridlock Demonstration System, which was the first system to provide automatic sensor registration for the fleet and which, with the introduction of autocorrelation, was deployed in the fleet as two operational systems, the Shipboard

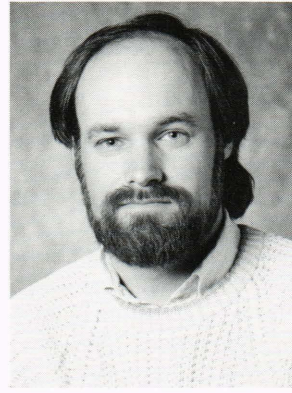
Gridlock System and the Shipboard Gridlock System with Auto Correlation. He was next involved in the design of the AutoID system, which implements automatic identification using radar track data. More recently, Dr. Miller has been the lead engineer on an electronic warfare support measures (ESM) tracker project that applies automated radar tracking techniques to ESM.





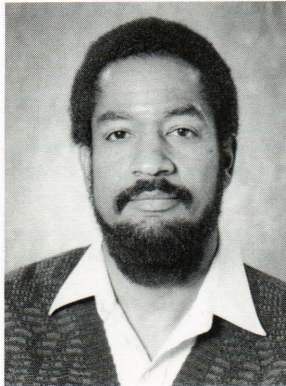
EDWARD P. LEE, project engineer for the Battle Group Anti-air Warfare Coordination (BGAAWC) program in APL's Fleet Systems Department, served 14 years in the Navy, after which he joined the Pacific Missile Test Center (PMTC), Pt. Mugu, California. At PMTC, Mr. Lee contributed to the development of the Range Surveillance Center and was a member of the Mobile Sea Range Operations Team for 5 years. With subsequent stints at Litton and then the Naval Ship Weapon System Engineering Station, he acted as project engineer for the New Threat Upgrade AN/SPS-48E

and AN/SYS-2 development. In 1982, he joined APL as test and evaluation engineer for the Detection Data Converter development, an improvement to the AN/SPS-48C radar, which provided fully automatic tracking for this radar. He then became project engineer for the SGS development and fleet introduction efforts, developed the AutoID system, and is currently involved in numerous other BGAAWC system development and/or improvement efforts at APL.



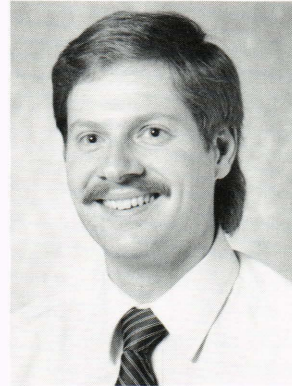
KENNETH D. BROCKMAN was born in Portland, Oregon, in 1955. He received his B.S. degree in electrical engineering from Oregon State University in 1978. From 1978 to 1982, he worked on the design and testing of automatic flight control systems for the 757/767 aircraft at the Boeing Commercial Aircraft Company, Seattle, Washington. From 1982 to 1984, he was employed by RCA Missile Systems Division, Moorestown, New Jersey, where he worked on the design of the Aegis Combat System implementation of the Gridlock Demonstration System and on the operator display and communications interface for the Autonomous Acoustic Array Project. In 1984, he joined the Anti-Air Warfare Systems Engineering Group at APL and has worked on the Shipboard Gridlock System with Auto Correlation (SGS/AC) system design in the development of surface and 2-D gridlock. He is now the lead engineer for the 2-D implementation of SGS/AC.

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ALAN B. JOICE, section supervisor in the Anti-Air Warfare Systems Engineering Group in APL's Fleet Systems Department, received a B.S. degree in electrical engineering from Drexel University in 1970 and an M.S. degree in electrical engineering from The Johns Hopkins University in 1984. Employed at APL in 1970, Mr. Joice was involved in the design and test of Naval Tactical Data System (NTDS) equipment and interfaces and was responsible for the installation and testing of the New Threat Upgrade NTDS equipment at APL. More recently, he was involved in the design and test of autogridlock systems and led the development of the E-2C version of the APL-developed gridlock system. Mr. Joice is now leading a project to develop new mechanisms to improve the battle group commander's ability to coordinate anti-air warfare engagements. His primary area of expertise is in naval combat system engineering and analysis.

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DAVID I. FURST was born in Harrisburg, Pennsylvania, in 1957. He graduated from Gettysburg College in 1979 with a B.A. degree in physics. He attended Pennsylvania State University and received an M.S. degree in low-temperature physics in 1982 for experimental research in the critical point phenomenon of pure fluids. Mr. Furst joined APL in 1982 and began work in the Combat System Integration Group of the Fleet Systems Department. After participating in the Fall 1982 Associate Staff Training Program, he returned to his former post, which has since become the Sensor

Data Integration Section of the Anti-Air Warfare System Engineering Group. Mr. Furst has worked in the areas of statistical analysis and optimal estimation theory related to gridlock, automatic correlation, and tracking. He is now involved in developing an automatic tracking system for the AN/SLQ-32, a passive shipboard sensor.