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Network-Centric Operations Case Study

Air-to-Air Combat With and Without Link 16

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Prepared for the Office of Force Transformation in the Office of the Secretary of Defense

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Summary

In the mid-1990s, the U.S. Air Force at the request of Congress conducted the Joint Tactical Information Distribution System (JTIDS) Operational Special Project. In this exercise, the capabilities of F-15 air superiority aircraft equipped with voice-only communications were compared with F-15s equipped with voice and JTIDS Link 16 data link communications in tactical air-to-air combat. More than 12,000 sorties were flown in this special project. Blue offensive counterair packages composed of these F-15s ranged in size from two to eight aircraft. In all cases, the packages were controlled and cued by Airborne Warning and Control System (AWACS) aircraft. The size of the engagements ranged from two Blue fighters on two Red fighters to eight Blue fighters on 16 Red fighters. Engagements occurred during daylight and night conditions. The primary independent variable was whether the Blue F-15s were equipped with the Link 16 data link or with conventional voice communications only. The capability of the Red aircraft remained consistent during the project.

On average, Blue offensive counterair packages equipped with Link 16 achieved a two-and-a-half times improvement in kill ratio (Red aircraft to Blue aircraft "destroyed"), both during the day and at night. However, it was unclear how and why this significant improvement in force effectiveness arose. The aim of this study is to understand whether this increase in combat effectiveness stemmed from the network-centric capabilities of F-15 aircraft equipped with Link 16 and fighter pilots able to effectively use data link communications.

The original Network-Centric Warfare (NCW) hypothesis posits the following relationships between twenty-first century information technologies, information sharing, and warfighting capabilities:

- "A robustly networked force improves information sharing
- "Information sharing enhances the quality of information and shared situational awareness
- "Shared situational awareness enables self-synchronization, and enhances sustainability and speed of command
- "These, in turn, dramatically increase mission effectiveness." (Alberts and Garstka, 2001.)

The Network-Centric Operations Conceptual Framework (NCO CF), developed by Office of Force Transformation (OFT) and the Office of the Assistant Secretary of Defense for Networks and Information Integration (OASD [NII]), provides a more detailed and precise elaboration of the NCW hypotheses.[1] It includes NCO capability concepts (such as the degree of networking, degree of information sharing, and situational awareness) and hypotheses for how these concepts relate to and influence each other. The result is an interlinked set of NCO capabilities that describe how they in combination can lead to improvements in overall military force effectiveness. Importantly, the NCO CF describes subsidiary attributes and metrics for assessing NCO capability concepts, making it possible to determine whether and how possession of a particular NCO capability relates to improvements in force effectiveness. Figure S.1 shows a top-level view of the NCO CF, including its top-level NCO capability concepts and the hypothesized interactions between them.[2] All linkages reflect positive relationships; for example, it is hypothesized that

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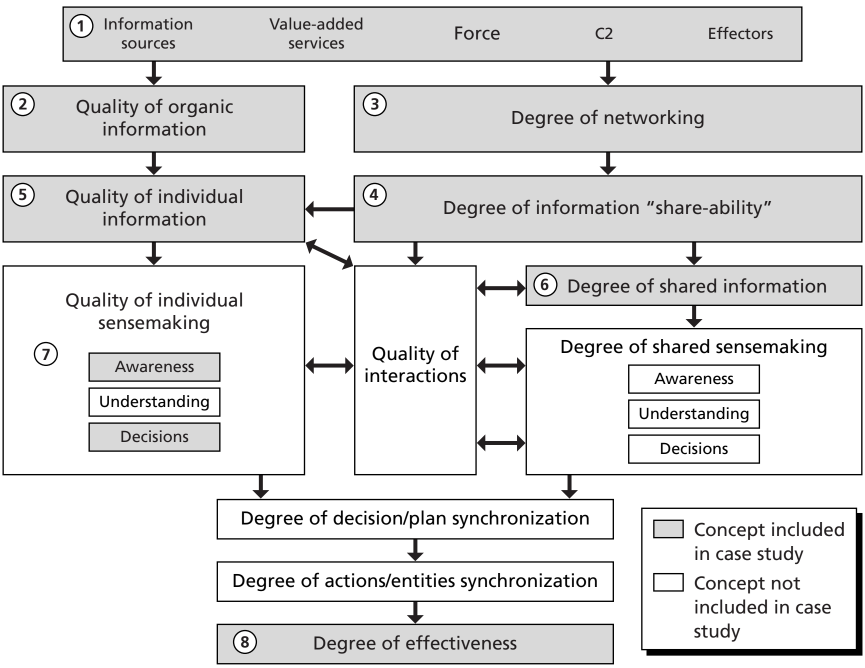
[1] Note that we use the terms NCO and NCW interchangeably in this report.

[2] The NCO CF is described in Signori et al. (2002); Evidence Based Research, Inc. (EBR) (2003); and Signori et al. (2004). Major concepts of NCO are described in Alberts, Garstka, and Stein (1999) and Alberts et al., (2001).

an improvement in the quality of information will improve the quality of situational awareness.

OFT and OASD (NII) tasked RAND to undertake a study to apply the NCO CF to the air-to-air combat mission. The primary objective of this case study is to understand whether the relationships between NCO capabilities hypothesized to exist in the NCO CF are valid for this particular military mission area and to determine how NCO capability improvements may lead to increases in military force effectiveness in air-to-air combat. In other words, our purpose was to "learn by doing" by applying the NCO conceptual framework to a specific mission.

Figure S.1
The NCO Conceptual Framework and Its Application to Air-to-Air Combat



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The air-to-air combat mission was chosen as an initial case study because it can involve relatively simple tactical engagement situations with a small number of aircraft. We anticipated it would be relatively easy to apply the NCO CF to simple tactical engagements. We were also fortunate that a source of quantitative force effectiveness data was available for this mission area. We were able to utilize data from the Joint Tactical Information Distribution System (JTIDS) Operational Special Project (Hq. USAF, 1997). Of particular interest is that the JTIDS project found that fighter aircraft in air-to-air engagements were significantly more effective when equipped with the Link 16 datalink than when equipped solely with voice communications. Specifically, Link 16–equipped fighters saw approximately a two-and-a-half times improvement in the kill ratio (Red aircraft to Blue aircraft shot down), both during daylight and nighttime conditions. This report examines whether the NCO CF can explain this major increase in mission effectiveness.

Figure S.1 showed the NCO CF top-level concepts that serve as the foundation for this case study, with the numbers indicating the order in which they are addressed in this report. The components of individual sense-making are shaded separately: we incorporate the quality of individual awareness and quality of decisions concepts but not the quality of individual understanding concept. Other concepts we focused on relate to physical NCO capabilities–notably the degree of networking and the resulting quality of information the pilots obtained from their organic sensors as well as from the network to which they are connected (see the various information concepts listed in Figure S.1). On the other hand, we did not employ the quality of interactions or sense-making concepts because we lacked data for these measures at the time the study was conducted. It is important to note that these concepts represent activities that take place in the cognitive domain (i.e., mental processes) and the social domain (i.e., interactions, such as conversations, between warfighters) and are difficult to evaluate directly.

Mission Capability Packages and Networking.

In the live flight operational exercises examined as part of the JTIDS Operational Special Project, F-15 fighter packages of two to eight aircraft flew against equal size or larger packages of enemy aircraft. We shall designate these fighter aircraft packages mission capability packages (MCPs).

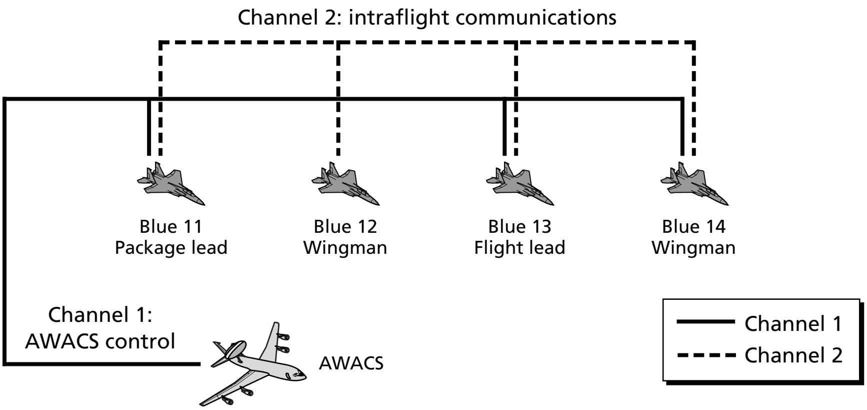
Two alternative Blue MCPs flew against the same Red MCPs in these live flight exercises. The Blue MCPs had different networking capabilities but were otherwise identical. One Blue MCP was equipped with the Link 16 digital data communications network, while the other had only voice communications. The Red fighters that participated in these live flight operational exercises had voice only communications.

Voice Networks

Figure S.2 illustrates the voice channel structure typically employed by Air Force fighters, in this case for an MCP with four fighters. Pilots each monitor two separate voice channels. AWACS broadcasts aircraft track information on Channel 1 to the Blue aircraft. The four fighter aircraft communicate among themselves on Channel 2. Each fighter pilot listens to two channels at a time, and only one aircraft pilot can speak on a channel at a time.

Air Force pilots have developed a voice coding scheme that allows pilots and AWACS flight controllers to transmit approximately one aircraft track about three times every ten seconds. We use ten seconds as the air picture track update cycle time because this is the rate at which the AWACS radar antenna rotates or performs one complete surveillance cycle of the battlespace. So, in principle, F-15 fighter pilots can receive updated air track information from AWACS every ten seconds, if AWACS flight controllers have the time to verbally transmit this information over the voice network every radar sweep and if there is "time available" to transmit the information over

Figure S.2
Typical Voice Channel Connectivity



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the voice channel (i.e., if there is no contention for the voice channel).

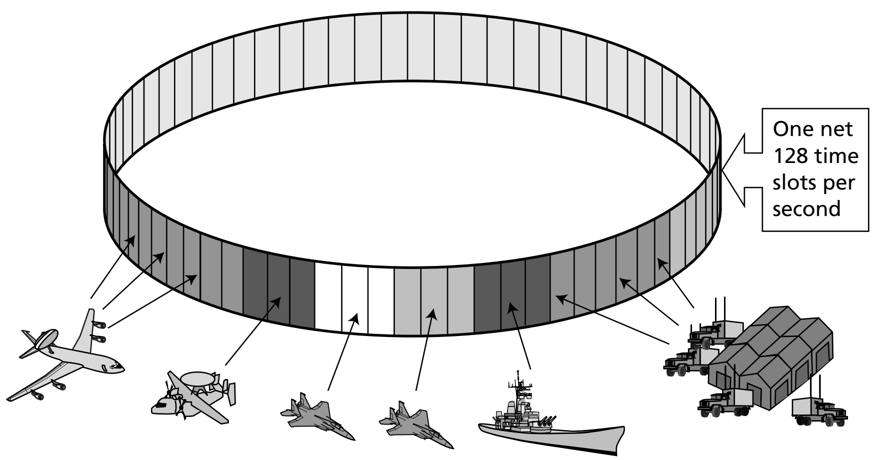
The pilots must interpret the spoken information they receive on their voice radios and build a mental three-dimensional "picture" of the positions and velocities of reported aircraft. This is known as developing situational awareness of the battlespace and is a persistent activity because of the dynamic nature of air combat. While fighter pilots generally have the mental ability to keep air track information in their minds for long periods, the utility of this information decreases as an air track "age" grows. An air track with an age of ten seconds or more has little utility because the pilot will have only a vague idea where the fast-moving jet fighter may be (the object that corresponds to the air track), especially at close ranges. We approximate the process of removing old information from a fighter pilot's mental map or "common operational picture" of the battlespace in the following way: air tracks older than the AWACS update rate are "dropped" on the grounds that the tracked plane will have moved far enough in ten seconds to make the pilot's mental air track position and velocity estimate too inaccurate to be useful in a high-speed tactical air combat engagement.

Link 16 Data Communications Network

Link 16 is a wireless data communications system that provides air track and other information to fighter aircraft, other weapons platforms, and command and control (C2) nodes equipped with JTIDS and Multifunctional Information Distribution System (MIDS) communications terminals. Link 16 uses a time-division multiple access (TDMA) wireless network structure and a jam-resistant, frequency-hopping waveform. This networking structure is illustrated in Figure S.3. In this type of network, each participant (or network node) can receive all transmissions made by other network participants.

Fighters equipped with Link 16 can receive air track information from other neighboring fighter aircraft and from AWACS (if AWACS is within a line of sight of the fighter). A Link 16 network is composed of 128 time slots per second, with each slot capable of

Figure S.3
Link 16 Network Connectivity



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describing a single airplane track to a high degree of accuracy. Link 16 air tracks received by a particular fighter from other aircraft are shown on a display screen in the cockpit along with air tracks detected by the aircraft's organic sensors. Therefore, each fighter pilot in a Link 16–equipped MCP can display nearly the same air track information or the same picture of the battlespace.

Information "Share-Ability" and Quality of Information

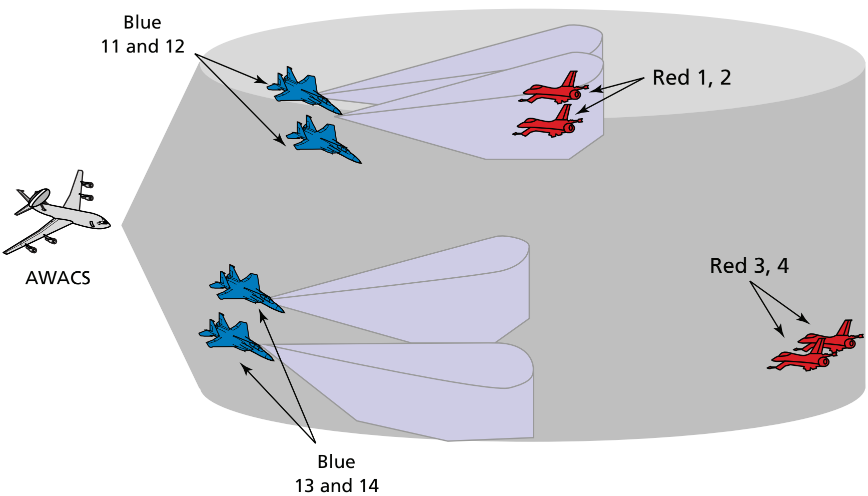
The "degree of information share-ability" concept describes how well individual pieces of information can be shared through use of the MCP's networking capabilities. In comparison to voice-only communications, the Link 16 network acts as an information multiplier; what is detected by one aircraft (either by AWACS or by a fighter) is immediately shared with all other fighters in the MCP precisely and in near real time. In contrast, voice transmissions are relatively slow (maximum of three track updates every ten seconds across an MCP voice channel), meaning that only a small fraction of the detected information can be shared. Further, voice communications introduce errors, either in the verbal communications themselves or because of radio noise or interference.

Consider the early stages of an air-to-air combat engagement shown in Figure S.4. In the tactical engagement, four Blue fighters engage four Red fighters. The four Blue fighters are provided threat warning information by AWACS and may be vectored by AWACS to engage particular threat aircraft. The figure illustrates the "opening gambit," or early stages of the engagement, which is a key part of the engagement recognized as strongly influencing the final outcome, as the Blue aircraft have an opportunity to maneuver for highly advantageous positions prior to engaging the Red aircraft directly. Here, the AWACS aircraft has radar coverage of the entire battlespace. Two of the Blue fighters (Blue 11 and Blue 12) have radar locks on two of the Red fighters (Red 1 and 2). Two of the Red aircraft (Red 3 and 4) are out of radar range for any of the Blue fighters and are on the very edge of the battlespace but are approaching their attack positions rapidly and are detected by AWACS.

We calculated the quality of information across the MCP for the engagement geometry shown in Figure S.4, for both an MCP with Link 16 and an MCP with voice-only communications. Note the use of the term "information" to indicate that it includes information available to the pilot of a particular aircraft from both organic sensors and the network. Figure S.5 compares quality of information scores for each Blue aircraft in both the voice-only and Link 16–equipped MCPs along four metrics (all normalized between zero and one):

- Completeness (Detection) is the percentage of all air tracks in the engagement (four Red and five Blue aircraft) that the Blue

Figure S.4
Early Stages of a Tactical Engagement



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aircraft either detects directly or has reported to it in the last ten seconds;

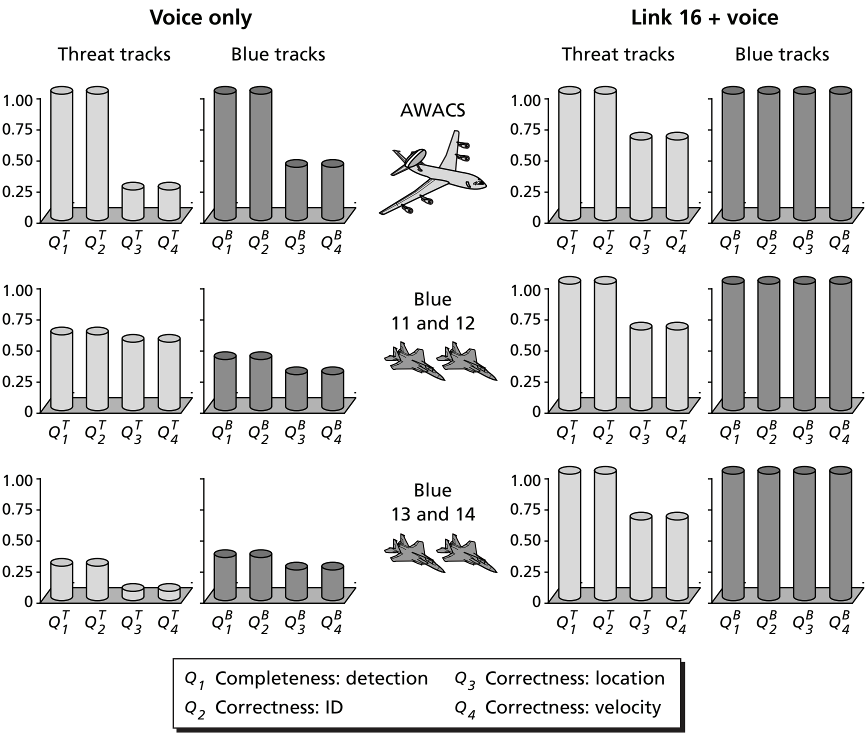
- Correctness (Identification) is the percentage of the air tracks for which the Blue aircraft has correct combat identification (ID)—i.e., Red, Blue, or neutral/civilian aircraft. If the air track ID is correct, a score of 1.0 is given. If it is incorrect or designated as unknown, a score of zero is given.
- Correctness (Location) is the percentage of air tracks for which the Blue aircraft has a location report (either from direct detection or network communications links). If the location report is less than one second old, it is considered to be "near real time," allowing for precise maneuvering and cuing fire control systems, and has a value of 1.0. If the report is between one and ten seconds old, it is considered to be "non–real time," suitable only for general cuing, and has a value of 0.25. If the report is older than 10 seconds, it is give a value of 0, as described earlier.
- Correctness (Velocity): Velocity is the percentage of air tracks for which the aircraft has a velocity report. As with Correctness (Location), the velocity report has value 1.0 if it is less than one second old, 0.25 if it is between one and ten seconds old, and 0 if it is older than that.

As shown, Blue aircraft in the Link 16 equipped MCP had much higher quality of information scores than the voice-only MCP, especially for the Location and Velocity metrics (which rely heavily on precise, real-time air track updates).

Shared Awareness and Decisionmaking

Interviews with experienced pilots revealed that the improved quality of information under Link 16 improved situational awareness and subsequent decisionmaking in two ways. First, in general, the pilots

Figure S.5
Comparing Quality of Shared Individual Information Across MCPs



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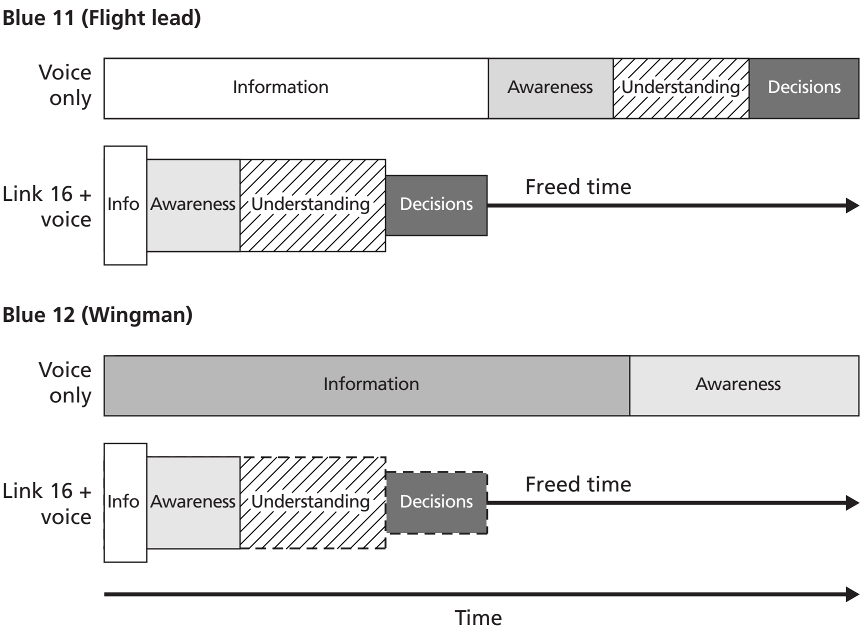
with access to the Link 16 network reported spending less time building situational awareness (i.e., determining where the Red and Blue aircraft are) than pilots with access only to the voice-only network. In the voice-only network, pilots had to continually listen to voice traffic describing air tracks, mentally convert each description into a velocity and location, predict where the aircraft would likely be over time based on the last report, and perform these mental calculations while listening to further incoming reports. Formal interviews were conducted with two pilots who had experience with Link 16–equipped aircraft. One of these pilots was a key participant in the JTIDS operational special project. In addition, we have discussed the findings of this report with four other pilots who have had experience with Link 16–equipped aircraft and with the new tactics Link 16 enables. This process of gaining awareness was described as slow (restricted by voice transmissions), mentally taxing, and potentially error-prone. Further, because the manual mental process of building awareness is error-prone under the stressing conditions of combat, pilot situational awareness information likely will not be entirely common across the MCP. In other words, situational awareness is shared and interpreted imperfectly among pilots over voice channels.

In contrast, in the Link 16 network, pilots are presented with a continually updated image visually displaying the precise positions and velocities of all detected aircraft in the battlespace. The resulting process of gaining situational awareness was much faster, almost automatic (no mental calculations required), and accurate. The resulting time compression in obtaining information and awareness with Link 16 is shown in Figure S.6. This freed time could be used to consider more alternative courses of action, which will tend to lead to better decisions, and make more decisions in a given period of time, which (assuming the decisions are reasonable) should lead to more targets destroyed. Notably, the freed time also allows the wingman time for sense-making and making decisions to engage targets, as opposed to spending virtually all their time gathering and monitoring critical information as in conventional doctrine.

Second, the pilots were able to improve execution of air combat tactics that were enabled by taking advantage of their increased awareness as well as the increased time they had available for decision-making. From the interviews, we have identified four broad types of improved tactics for air-to-air combat. These tactics are illustrated in Figure S.7.

The first of these is simply an increased number of engagements in the same period. This tactic is possible because pilots with Link 16 can quickly recognize the most efficient attack trajectories. This is an important consideration because (according to the pilots) the fighters

Figure S.6
Decision Speed and Competitive Advantage with Link 16



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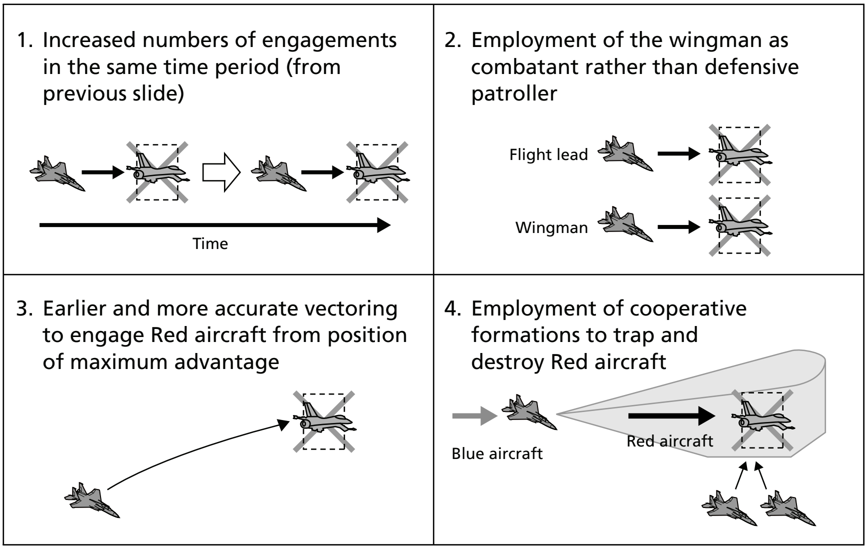
only have a limited time to engage before they run out of fuel and must return to base.

The second is the employment of the wingman as a combatant rather than as a defensive patroller. With Link 16 and good combat ID capabilities, the location and identity of threat aircraft are apparent to pilots of all Blue aircraft. The flight lead has more options for employing the wingman as a primary shooter because of the higher levels of individual and shared understanding of the engagement, effectively doubling the firepower. Wingmen do not have to take up defensive positions to hedge against possible attacks from threat aircraft advancing from unknown locations.

The third is the use of other planes' track information to vector earlier and more accurately, which allows a Blue fighter to enter an

Figure S.7
Improved Air-to-Air Tactics Execution Enabled by Improved Awareness



SOURCE: Interviews with fighter pilots experienced with Link 16.
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engagement from a position of maximum advantage, before the Blue fighter's radar (or the Red plane's radar, for that matter) can detect the engaging plane. This tactic takes maximum advantage of AWACS or other offboard sensor threat-reporting.

The fourth is the use of "ambush" combat air patrols (CAPs) and the use of terrain to trap and destroy Red aircraft. Because all Blue aircraft locations are known by all Blue fighter pilots—even if those aircraft are operating in voice communications or Identification, Friend or Foe (IFF), transponder silence—they have more options to engage targets. One example of an "ambush CAP" tactic is when a Blue fighter chases a Red fighter towards other Blue aircraft. The latter Blue aircraft have their radars turned off (or are hiding in a canyon) so the Red fighter is not likely to know that the latter Blue aircraft are present. Then, when the Red aircraft is chased into range, the other Blue fighters will suddenly engage the Red fighter, surprising the Red pilot and likely destroying the Red fighter with minimal risk to Blue aircraft. This latter tactic is an example of tactical self-synchronization enabled by the Link 16 network.

Mission Effectiveness

Loss exchange ratios (number of Red aircraft killed divided by the number of Blue aircraft killed) from the JTIDS Operational Special Project are shown in Table S.1. It is based on the results of 12,000 training sorties in tactical air-to-air combat. On average, Link 16 led to a two-and-half times improvement in the kill ratio (Red aircraft to Blue aircraft shot down), during both daylight and nighttime conditions.

The analysis presented above indicates in these tactical engagements the better decisionmaking and improved tactics execution by Blue fighter pilots were enabled by improved situational awareness provided by Link 16. This in turn led to the Link 16–equipped MCPs' improvements in kill ratios. This chain of inferences is verified by our interviews with experienced pilots. For some steps of the NCO inference chain, quantitative data were not available—e.g., data monitoring how pilots gained awareness and made decisions during the engagements. Nevertheless, pilot interviews substantiate the validity of the inference chain described in the NCO framework for this mission area.

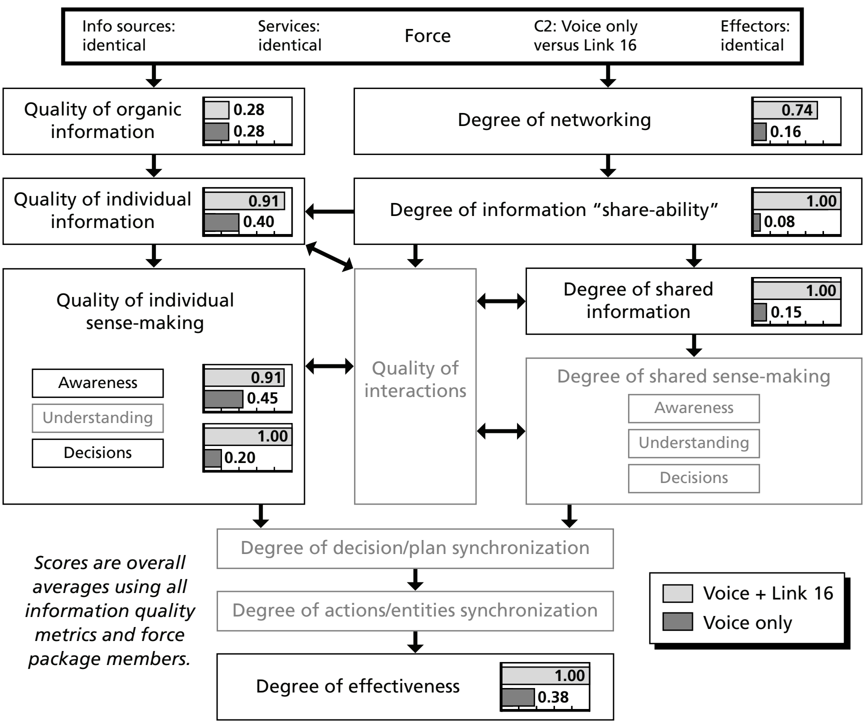
Table S.1
Results of the JTIDS Operational Special Project

	Kill Ratio	
	Voice Only (MCP 1)	Voice Plus Link 16 (MCP 2)
Day	3.10:1	8.11:1
Night	3.62:1	9.40:1

Conclusions

Figure S.8 presents averages of the NCO CF metric scores we calculated in this case study across the MCPs. As shown, despite starting with similar airframes, training, doctrine, and organic sensing capabilities, the Link 16–equipped MCP was able to take advantage of the information shared within the MCP through Link 16 and voice networks far more effectively than the voice-only MCP. As hypothesized by the NCO tenets, the robustly networked force enabled via Link 16 improved information sharing and the resulting quality of information, which enhanced shared situational awareness, which in turn

Figure S.8
Summary Comparison of MCPs Using Average Scores



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enabled self-synchronization (in this case study, as measured by the ability to make improved decisions and execute improved tactics) and which resulted in dramatically increased mission effectiveness as measured by the kill ratios.

We have applied the NCO CF and developed quantitative estimates for key NCO metrics within the framework. We have examined several inference chains that run through the NCO CF and have found them to be consistent with the results of a key air-to-air live flight experiment and with the observations of experienced combat pilots.

Finally, we recommend additional case studies be performed of more complex mission areas and that extend this analysis of the air-to-air mission area further to provide further understanding of NCW and the NCO CF, and particularly of the cognitive and social domain concepts, attributes and metrics covered in the framework (e.g., cognitive measures of sense-making and interactions).