**MILITARY MEDICINE,** 177, 7:863, 2012

# The Future of Vertical Lift: Initial Insights for Aircraft Capability and Medical Planning

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**ABSTRACT** The U.S. Army continues to evaluate capabilities associated with the Future of Vertical Lift (FVL) program—a future program (with a time horizon of 15 years and beyond) intended to replace the current helicopter fleet. As part of the FVL study, we investigated required capabilities for future aeromedical evacuation platforms. This study presents two significant capability findings associated with the future aeromedical evacuation platform and one doctrinal finding associated with medical planning for future brigade operations. The three results follow: (1) Given simplifying assumptions and constraints for a scenario where a future brigade is operating in a 300 × 300 km$^2$, the zero-risk aircraft ground speed required for the FVL platform is 350 nautical miles per hour (knots); (2) Given these same assumptions and constraints with the future brigade projecting power in a circle of radius 150 km, the zero-risk ground speed required for the FVL platform is 260 knots; and (3) Given uncertain casualty locations associated with future brigade stability and support operations, colocating aeromedical evacuation assets and surgical elements mathematically optimizes the 60-minute set covering problem.

## INTRODUCTION

The U.S. Army continues to evaluate capabilities associated with the Future of Vertical Lift (FVL) program—a futures program (with a time horizon of 15 years and beyond) intended to replace the current helicopter fleet.[1] As part of the FVL study, we conducted a DOTMLPF (doctrine, organization, training, maintenance, leadership, personnel, facilities) assessment using a mixed-methods (quantitative and qualitative) approach to determine gaps in the current force structure and solutions for future force design.[2] In another part of the FVL study, we investigated the required capabilities (airspeed, altitude, cabin space, etc.) for future aeromedical evacuation platforms. Previous studies and research efforts have tackled problems concerning aeromedical evacuation asset requirements, allocation, and emplacement decisions using different modeling, simulation, and optimization techniques.[3–6] During the FVL study, however, doctrinal ideas and insights emerged, and some of these insights are particularly poignant for military medical planners. The Medical Evacuation Proponency Directorate (MEPD) funded this FVL study as a subset of ongoing analyses.

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This article was presented at 2011 Annual Meeting of the Institute for Operations Research and the Management Sciences, Charlotte, NC, November 16, 2011.

### *Background*

For the FVL planning process, the primary fighting forces are Army brigades, a force of 3000+ personnel, according to Colonel Robert Mitchell, Director of the MEPD. For the FVL analysis, the area of operations for the future brigade is a 300 km by 300 km (162 nautical miles [NM] by 162 NM) square box (slightly more area than the state of Maine), possibly deriving from an Army white paper written in 2004 as referenced by.[7] This box assumes unequal projection of power since the distance from the brigade center to any corner is 212 km (114.5 NM), whereas the closest distance from the center to the side is 150 km (81 NM). As part of the study analysis, we assumed that the brigade might also exert uniform radial projection of power over a more conservative area, a circle of radius 150 km (81 NM) corresponding to the shortest distance from the center of the brigade to its force projection boundary. The reason for this assumption and secondary analysis is that brigades operating independently in stability and support operations might project power uniformly from the headquarters. Additionally, the planning assumption of square battle space may perhaps be a vestige of Cold War planning, where the assumption of a linear battle was commonplace. Figure 1 depicts both the square box and circular arrangements analyzed for this study.

Analysis of required FVL support for a brigade operating in either square or circular configurations includes the assessment of aeromedical evacuation. One of the known requirements for aeromedical evacuation is the 1-hour evacuation standard imposed by the former U.S. Secretary of Defense Robert Gates. The reason the former Secretary of Defense provided this standard is best expressed in his own words:

> "The standard for medical evacuation [from the battlefield] in Iraq was an hour. . . . .Everybody had to be 'MedEvaced' within an hour. But Afghanistan is a lot

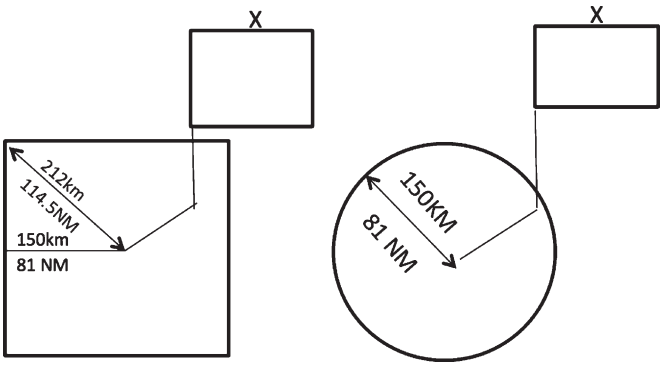


**FIGURE 1.** Shown are 2 possible arrangements of the future brigade. The brigade headquarters are depicted using military symbols as flags with an "X" above them and a diagonal line pointing to its location. The left diagram shows force projection as a function of a square box, whereas the right shows force projection as emanating uniformly from a circle. The distances in kilometers and nautical miles are shown.

> tougher terrain. And so it came to my attention that they had settled on two hours. And I said: 'Bulls–t. It's going to be the same in Afghanistan as in Iraq.' And the medical guys, the medical bureaucracy, pushed back on me and said: 'No, no, it really doesn't matter.' And I said: 'Well, if I'm a Soldier and I'm going out on patrol, it matters to me.' And so we sent a bunch of new helicopters, three new field hospitals, a whole bunch of stuff. And so now we have the 'golden hour' in Afghanistan."[8]

This standard requires that the time between medical evacuation notification to the time of patient drop-off at a surgical facility must not exceed 60 minutes. This standard most probably derived from the concept of the "Golden Hour," a maligned conjecture that survivability of seriously wounded individuals decreases dramatically after 60 minutes.[9] Regardless of the merit of this conjecture, the certainty in planning (and potential psychological advantage for those participating in combat, expressed admirably by the former Secretary of Defense) makes the 60-minute directive an outstanding tool for medical planning and for analysis of alternatives.

### *Purpose and Research Question*

The U.S. Army Medical Department (AMEDD), specifically the MEPD, was asked to evaluate capabilities required for the FVL program. The task assigned to MEPD is of significant importance as inclusion of aeromedical evacuation requirements into the future planning process would help ensure the acquisition of a capable life-saving vehicle. In previous acquisition efforts, the AMEDD did not have its requirements appropriately integrated. For example, according to Ronald Wilson, consultant for MEPD, the UH-60 aeromedical evacuation platform was initially unable to handle a "NATO-standard" litter. The current process, however, is well integrated.

MEPD received several requests for analysis. Part of the analysis required an assessment of the minimal FVL capability given doctrinal constraints, whereas another part required more holistic analyses of the entire aeromedical and aviation systems. Although we investigated several research questions, ideas and insights generated from 1 question were particularly relevant. That research question follows:

> "What FVL aircraft ground speed would ensure appropriate aeromedical evacuation coverage in current or future operations to support the mandated Secretary of Defense 1-hour evacuation standard given doctrinal combat brigade support areas?"

To answer this research question, we performed 2-dimensional and 3-dimensional geographical analysis. We viewed this problem as a "set covering problem" in 2 or 3 dimensions with uncertain (uniformly distributed) casualties. During this analysis, ideas and insights relevant to military medical planners emerged.

## METHODS

Investigation of this research question required an analysis of how casualties might occur. If a medical planner had perfect knowledge of where and when casualties would occur, then he or she would place appropriate treatment and evacuation assets as close as safely possible a priori. These casualty cluster areas and safe locations, however, are unknowable and exceedingly difficult to forecast accurately, at least in early operations. Because of this uncertainty, for initial medical planning we assume a uniform distribution of casualties across the battle space, which means that casualties might occur anywhere in the brigade with equal probability. Even if casualties are assumed to cluster around the maneuver brigade, a uniform distribution around that brigade is a typical assumption reflecting lack of knowledge.[5,6]

Before answering this research question, we also analyzed how might the surgical facility and evacuation assets be best located to maximize the coverage assuming flat terrain and zero wind conditions (adjustments for nonflat terrain and wind are discussed later). In other words, should evacuation assets be colocated with surgical facilities or positioned separately in geographically dispersed locations? This problem concerns maximizing over the long and short axes the area of an ellipse,

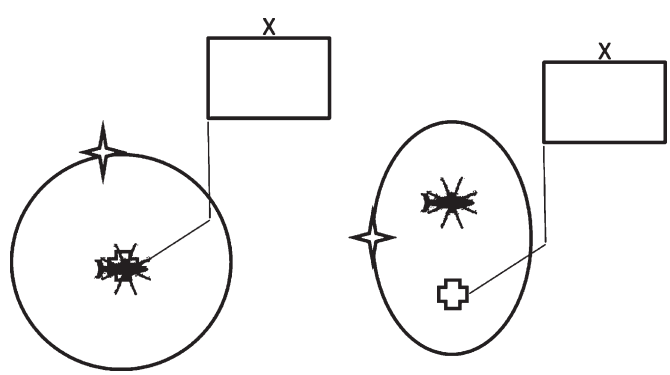


**FIGURE 2.** The diagram below illustrates the 60-minute boundary for 2 configurations, a circle and an ellipse. The circular boundary is 60-minute coverage to any patient on the boundary (illustrated with a 4-pointed star) with colocated assets. The ellipse is also 60-minute coverage; however, the assets are not colocated.

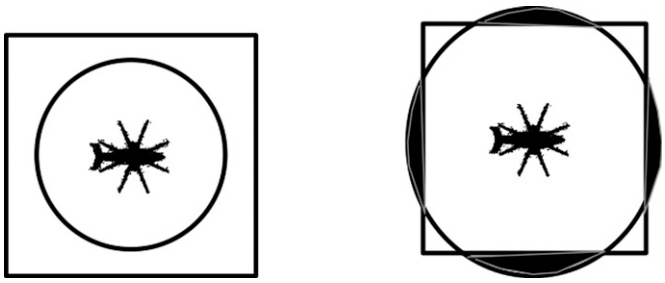

**FIGURE 3.** The square box represents the brigade coverage in both diagrams. The circle represents the evacuation coverage. In the box on the left, calculating the area left uncovered is trivial (area of the square minus area of the circle all divided by the area of the square.) In the box on the right, the formula is similar; however, the area of the four circular segments shown in black is subtracted from the numerator.

because by definition, an ellipse has 2 foci (e.g., the evacuation and surgical locations) and every point to the curved line connecting these foci is a fixed value (60 minutes of distance).[10] Given fixed and geographically disparate positions of the evacuation site location, *e,* and the surgical team, *s*, the ellipse derives from connecting these 2 locations and drawing the boundary, *b*, for all other distances radial from this point that make $e + s + b = 60$ minute boundary measured in distance.

Upon mathematical analysis of this problem, we found that colocating the surgical element with the evacuation element results in maximization of the area covered (see Appendix A). For establishing that colocation results in maximizing the covered area, the necessary and sufficient conditions are a gradient of zero at the optimal point and a negative definite Hessian (table of second partial derivatives).[11] Figure 2 illustrates area coverage based on aeromedical evacuation and surgical treatment.

By understanding that colocation of evacuation and treatment assets maximizes the area covered, we proceeded in providing decision support for aircraft speed considerations by calculating the brigade area left uncovered given certain airspeeds and round-trip distances. The importance of calculating the area uncovered over speeds and round-trip distances is that it provides military decision-makers the opportunity to assess

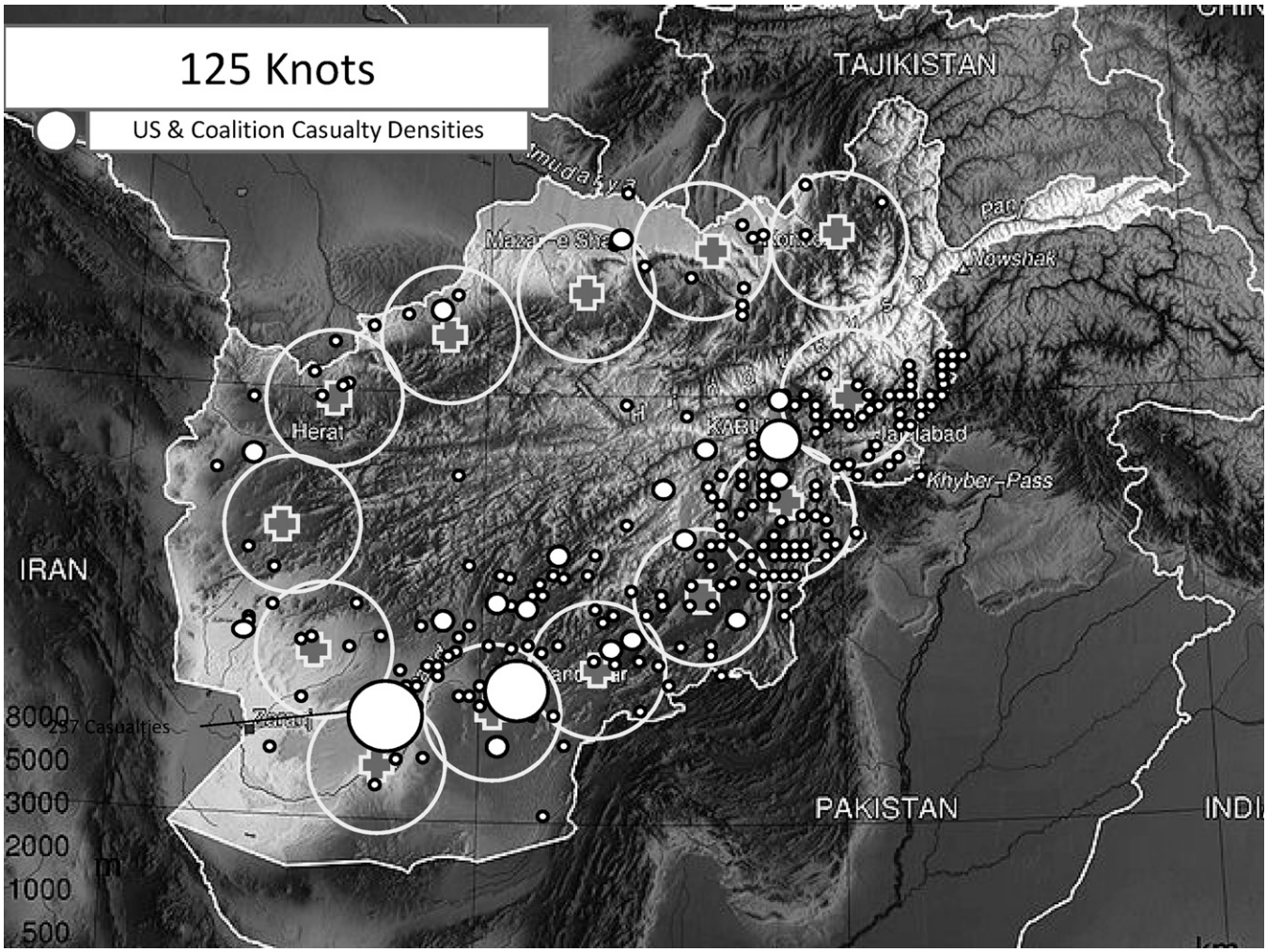


**FIGURE 4.** This map of Afghanistan contains an overlay of casualty densities (shown in white) recreated from CNN. The large, unfilled circles are illustrative of coverage areas for evacuation assets capable of achieving 125 knots ground speed and which are colocated with surgical elements. Thirteen coverage areas are hypothesized.

risk by addressing the question of what area would be uncovered if an aircraft with speed of X was selected for the aeromedical evacuation mission. This procedure was conducted for the analysis of the brigade occupying a square and a circle.

Certain flexible assumptions regarding aeromedical evacuation operations provided the basis for the final analysis. First, notification to aircraft run-up was fixed at 7 minutes based on recent reports in Afghanistan from Colonel Mitchell. Second, "patient packaging" (preparing the patient for movement) was set to 10 minutes. (Loading varies based on patient; however, this value is congruent with qualitative analysis from theater.) Third, patient drop-off time was set to 5 minutes. All of these times (run-up, loading, and drop-off) became flexible parameters in a decision support tool, so that decision-makers could evaluate other values. Finally, helicopter climb and descent are assumed nominal. For the initial analysis, a 60-minute boundary represents 48 minutes of actual travel time.

We generated the calculations for percent of area left uncovered based on round-trip distances from 0 NM to 229 NM (the maximum distance associated with a brigade operating in the square) and ground speeds from 100 NM to 400 NM per hour (knots). Mathematical calculations for percent of area uncovered were based on both square and circular arrangements (Fig. 3) (see Appendix B).

To account for the effect of terrain requires the assumption that the altitudes would be known a priori. Nonetheless, a simple method for estimating terrain considerations is to carve out segments by evaluating near-peak altitudes for any areas for which altitude is not assumed to be nominal and for which low-level traversing is impossible. The 60-minute boundary would then be calculated based on the ascent line (drawn from the aircraft location) and assumed climb speed coupled with the descent line (drawn from the location of peak elevation) and assumed cruise speed. Specific sectors would then need to have only segments carved out to adjust for the aircraft climb-out. Such adjustments are not needed when terrain is unknown, and the assumption that brigades would not reduce the size of their operating area regardless of terrain considerations is

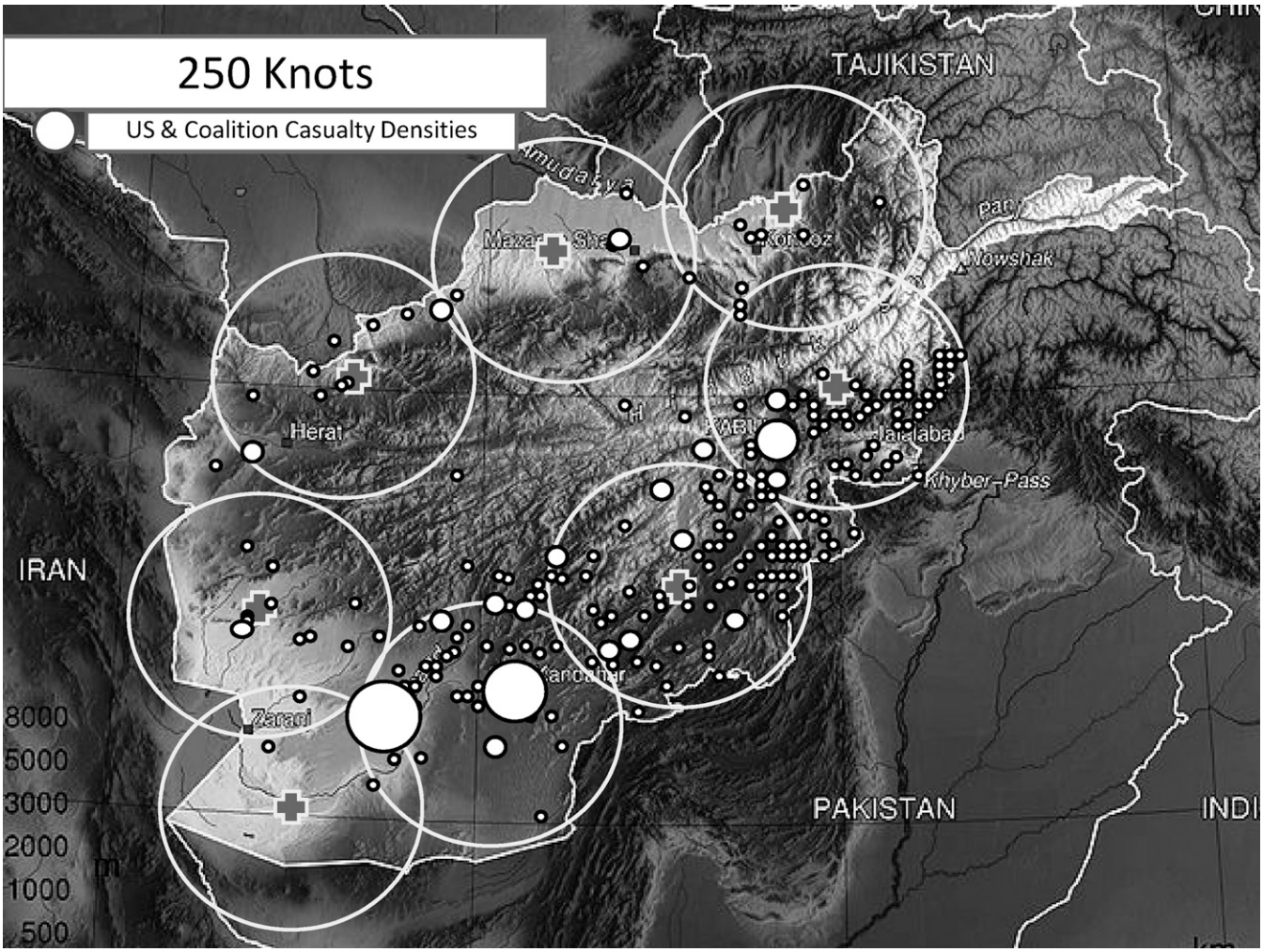


**FIGURE 5.** This map of Afghanistan contains an overlay of casualty densities (shown in white) recreated from CNN. The large, unfilled circles are illustrative of coverage areas for evacuation assets capable of achieving 250 knots ground speed and which are colocated with surgical facilities. Eight coverage areas are hypothesized.

fallacious as well. Without a priori knowledge of terrain, we used flat terrain as a base case for analysis.

## RESULTS

Using the previously stated assumptions and equations, we generated a decision support tool for evaluating area left uncovered, which provides military decision-makers risk analysis information. (The more area uncovered is a proxy for increased risk.) Appendix C depicts the results of the analysis. Given the assumptions previously stated, the aircraft ground speed necessary to cover all of the brigade operating space when the brigade is assigned a square is 350 knots, whereas the ground speed necessary for full coverage of the brigade in circular space is 260 knots. At 260 knots ground speed, 19% of the area of the brigade square remains uncovered.

To assist decision-makers in understanding the coverage capabilities of aircraft with different airspeeds, we designed maps of Afghanistan recreated from Cable News Network (CNN) casualty maps superimposed.[12] The map of Afghanistan, created with Generic Mapping Tools[13] and terrain data sets in 2005, is freely available from Wikipedia Commons.[14] Figures 4–6 are representative overlays for future airspeed capability of 125 knots, 250 knots, and 300 knots. The increased capability of aeromedical evacuation assets reduces the support locations required (and thus the associated logistical support footprint such as forward operating bases, refueling points, resupply points, and perhaps even the number of aircraft). In Figure 4, the mock-up map demonstrates that 13 locations (shown as circles) partially cover the casualty densities (shown as white blotches). The number of locations reduces to 8 and then 6 for Figures 5 and 6, respectively. Given that doctrinal emplacement of aeromedical evacuation assets is (at a minimum) in groups of 3, the resulting reduction in airframes required by increasing attainable ground speed from 125 knots to 300 knots is $(13 \times 3) - (6 \times 3) = 21$.

## DISCUSSION

Upon conclusion of this work, we returned to the initial research question: What FVL aircraft ground speed would ensure appropriate aeromedical evacuation coverage in current or future

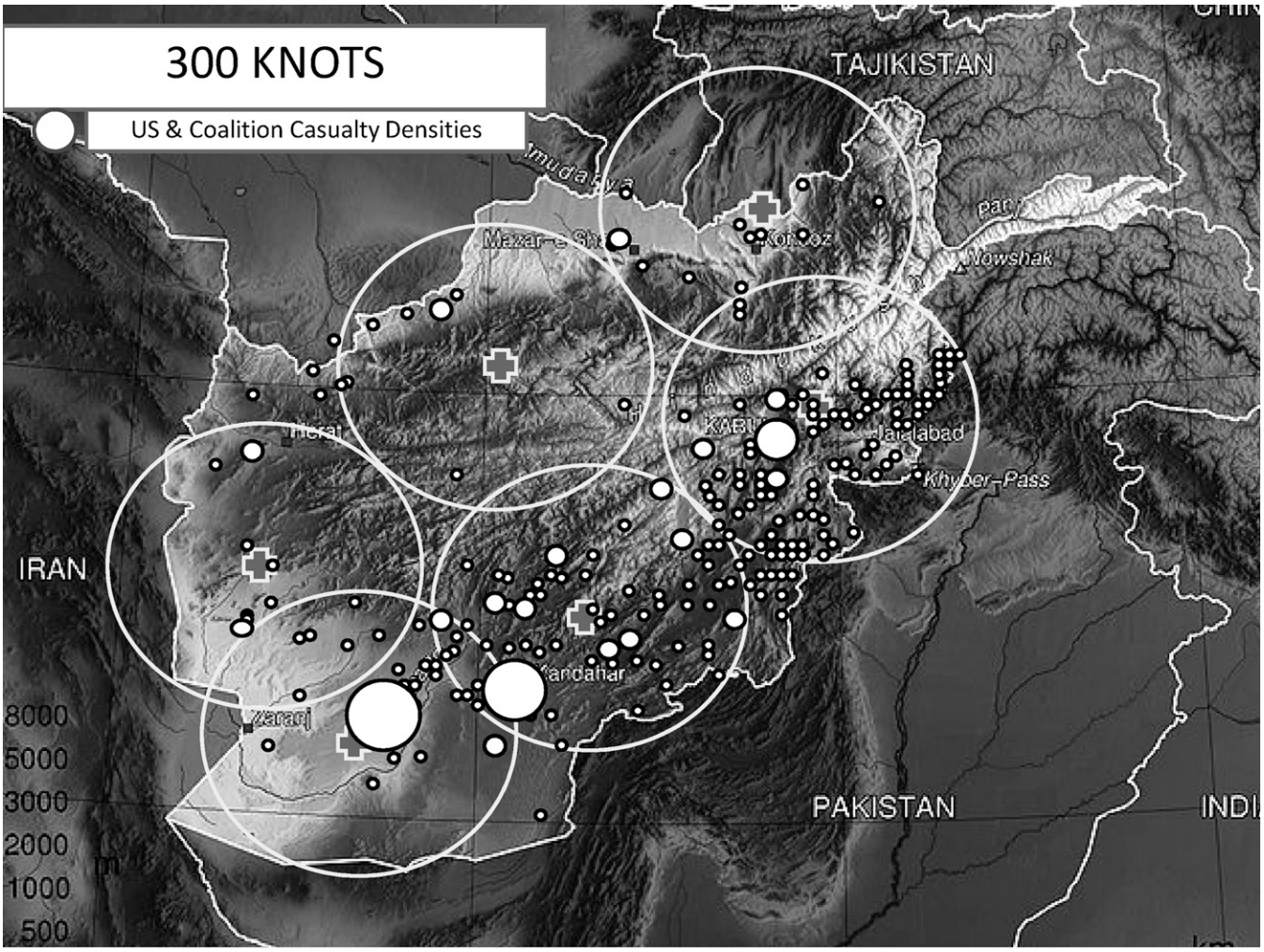


**FIGURE 6.** This map of Afghanistan contains an overlay of casualty densities (shown in white) recreated from CNN. The large, unfilled circles are illustrative of coverage areas for evacuation assets capable of achieving 300 knots ground speed and which are co-located with surgical elements. Six coverage areas are hypothesized.

operations to support the mandated Secretary of Defense 1-hour evacuation standard given doctrinal combat brigade support areas? Unconstrained and given the assumptions provided, the airspeed that ensures zero risk for brigade circular and square arrangements is 350 knots. Such an airspeed capability is certain to be associated with a significant cost factor. If the brigade influences battle space in a circle, then a ground speed of 260 knots would provide complete coverage over flat terrain. These 2 recommendations are zero-risk solutions; however, Appendix C provides the capability for decision-makers to evaluate risk by evaluating distance to be traveled (total) versus airspeed and time.

Because of the uncertainty involved with casualty estimation, our analysis only considered the uniform distribution of casualty clusters in the brigade operations space despite the casualty densities depicted in Figures 4–6. As a limitation to our work, therefore, we did not contrast our uniform distribution assumption with clusters of casualties in only two-thirds of the battle space. Additionally, our work did not account for the specific surgical facility capabilities and capacities nor the aeromedical evacuation requirements after casualty care at the surgical facility. Once the casualty receives proper medical treatment, we assume that the patient is either returned-to-duty or transferred to a higher level of care via a different evacuation platform.

Interesting to this analysis is the fact that the additional speed capability might allow for a reduction in the logistical and support footprint as shown by Figures 4–6. Any reduction, however, assumes that the footprint is a function of area support rather than casualty demand. In other words, casualty streams may require a larger logistical footprint. Additional assets and basing requirements offset risk associated with weather, environment, and the chaotic nature of military operations. Our analysis, however, does not consider differences in the types of logistical footprint (e.g., a single location of 6 evacuation assets versus 2 separate locations with 3 evacuation assets each). The potential reduction in logistical and support footprint of the evacuation assets is only one part of the equation. Building on the assumptions made, an increase in aircraft speed may have significant implications on the total number of surgical facilities needed in a given arena.

## CONCLUDING REMARKS

As part of this FVL study, we investigated the required capabilities for future aeromedical evacuation aircraft and developed a decision support tool for military medical planners in evaluating risk associated with aeromedical evacuation platform capability and coverage within the brigade operating space. In addition to the 2 significant capability findings previously discussed, we also uncovered 1 doctrinal finding associated with medical planning for future brigade operations. Specifically, we determined that colocation of aeromedical evacuation assets and surgical elements provide the optimum coverage for a single brigade when casualty clusters are indeterminable or random. These insights have proven extremely useful to military medical planners within the U.S. AMEDD.

## ACKNOWLEDGMENTS

We thank the Medical Evacuation Proponency Directorate of the Medical Capabilities Integration Center of the U.S. Army Medical Department Center & School, Fort Rucker, AL, who funded the research and analysis of this study.

### APPENDIX A

For completeness, the following demonstration is included (noting that the area of an ellipse is $\pi ab$ and that $C$ is any distance boundary associated with achievable time traveled):

$$\underset{a,b}{\text{Max}}\, f = \pi ab - C \tag{1}$$

$$\nabla f = \begin{vmatrix} \pi b \\ \pi a \end{vmatrix} = \begin{vmatrix} 0 \\ 0 \end{vmatrix}, \pi b - \pi a = 0, b = a \tag{2}$$

$$\nabla^2 f = \begin{vmatrix} 0 & \pi \\ \pi & 0 \end{vmatrix}, \Delta = -\pi^2 \tag{3}$$

Solving both systems of equations in the gradient (Eq. 2) results in $\pi b - \pi a = 0$, so $b = a$ is either a minimum or maximum. Checking the determinant of the Hessian (the discriminant) to ensure it is negative definite (Eq. 3) illustrates that $b = a$ maximizes the area of an ellipse. If $b = a$ (and letting $b = r$, then the area of that shape is $f = \pi r^2$, the well-known area of a circle. Therefore, colocating aeromedical evacuation aircraft and medical treatment facilities results in maximizing the area covered.

### APPENDIX B

For the square arrangement, the percent of area uncovered was a piecewise function based on radius, $r$:

$$g = \begin{cases} \dfrac{162\text{NM}^2 - \pi r^2}{162\text{NM}^2}, 0 < r \le 81\text{NM} & (4) \\ \dfrac{162\text{NM}^2 - \left(\pi r^2 - 4 * \frac{r^2}{2}(\theta - sin(\theta))\right)}{162\text{NM}^2}, \\ \theta = 2ar\ cos\left(\dfrac{81}{r}\right), 81\text{NM} < r \le 114.5\ \text{NM} & (5) \\ 1, r > 114.5\ \text{NM} & (6) \end{cases}$$

The numerator in Equation 4 simply takes the area of the brigade square and subtracts the area of the circle covered (assuming that no overlap exists). Dividing that numerator by the area of the square provides the proportion covered. The numerator in Equation 5 calculates the area of the square and subtracts the area of the circle less the area of the 4 segments that extend beyond the square. A single overlap is a circular segment with well-known area of $\frac{r^2}{2}(\theta - \sin(\theta))\frac{r^2}{2(\theta - sin[(\theta)).]}$ (See Figure 3). The denominator in Equation 5 represents the area of the square, and Equation 6 captures the circular coverage over the entire square.

The location of the "surgical-evacuation" team for the scenario described by Equation 4 is restricted only by ensuring that the team's coverage circle is completely inscribed by the brigade's operating area. For Equation 5, the "surgical-evacuation" team is assumed to be centered on the brigade, as centering ensures maximum coverage over the brigade square (proof omitted). Equation 6 assumes superscription.

For the brigade in circular arrangement, the proportion left uncovered is a simple piecewise function as shown in Equations 7 and 8:

$$h = \begin{cases} \dfrac{\pi 81^2 - \pi r^2}{\pi 81^2} = \dfrac{81^2 - r^2}{81^2}, 0 \le r \le 81\ \text{NM} & (7) \\ 1, r > 81\ \text{NM} & (8) \end{cases}$$

In Equation 7, the area uncovered is simply the complement of the area covered by the 60-minute aeromedical evacuation time divided by the area of the brigade's

operation. Any coverage exceeding the brigade circular area is represented by Equation 8. The location of the "surgical-evacuation" team in Equation 7 assumes inscription inside the brigade circle. Equation 8 assumes superscription, regardless of team location.

## APPENDIX C

**TABLE CI.** Distance, Speed, Delay vs. Transport Time

| Distance to Patient Then to Facility (Nautical Miles) | Aircraft Ground Speed in Knots (Nautical Miles/Hour) | | |