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Atmospheric Impacts Routing (AIR)

by Jeffrey O. Johnson

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14. ABSTRACT Atmospheric impacts on platforms and alternative routing options which consider environmental factors along a planned path of movement are of high importance during combat operations. Such options serve to improve survivability and movement efficiency of air and ground platforms and systems. Environmental factors which may adversely affect systems during combat operations along a projected path include adverse weather, threat activity, conflicting friendly operations, and other obstacles. The U.S. Army Research Laboratory's Battlefield Environment Division has developed the Atmospheric Impacts Routing (AIR) application, which calculates optimized routes in 3D space, avoiding adverse atmospheric conditions and other obstacles during mission execution. ARL's AIR web service will supplement the Air Force Weather Agency (AFWA) web services (AFW-WEBS) as well as the U.S. Army Tactical Airspace Integration System (TAIS) web service developments, incorporating TAIS airspace conflict detection services as input for route optimization.				
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Contents

List of Figures	iv
1. Introduction	1
2. Overview	1
3. AIR Functionality	2
4. A Source of Weather Impacts for AIR	6
5. Conclusions	7
6. References	8
Bibliography	9
List of Symbols, Abbreviations, and Acronyms	10
Distribution	11

List of Figures

Figure 1. Notional example of a 3D grid of “impacts.” The data from this 30×30×30 grid were used during some of the testing phases of the AIR application.	3
Figure 2. AIR output of two paths in Google Earth KML format: high risk and lower risk. The impacts used when the paths were calculated are shown as additional overlays.	5
Figure 3. Example output from AIRView (Windows application). Image shows both the Java 2D plot (foreground) and the Google Earth KML output (background).	5
Figure 4. Prototype MyWIDA Version 2 reference graphical user interface.	7

1. Introduction

Atmospheric impacts on platforms and alternative routing options, which consider environmental factors along a planned path of movement, are of high importance during combat operations. Such options serve to improve survivability and movement efficiency of air and ground platforms and systems. Environmental factors that may adversely affect systems during combat operations along a projected path include adverse weather, threat activity, conflicting friendly operations, and other obstacles. The U.S. Army Research Laboratory's (ARL) Battlefield Environment Division has developed the Atmospheric Impacts Routing (AIR) application and web service, which calculates optimized routes in 3D space, avoiding adverse atmospheric conditions and other obstacles during mission execution. ARL's AIR web service will supplement the U.S. Air Force Weather Agency's (AFWA) Air Force Weather Web Services (AFW-WEBS), as well as the U.S. Army Tactical Airspace Integration System (TAIS) web service developments, incorporating TAIS airspace conflict detection services as input for route optimization.

2. Overview

The AIR application is a replacement of the Army's earlier technology Aviation Weather Routing Tool (AWRT) described by Knapp et al. (2006). Developed from scratch, AIR's design allows it to be applied to both air and ground routing applications by its use of 4D data grids (3D grids over time) of "impacts." The impacts data may be areas of adverse weather or other environmental parameters that may be used to identify areas to be avoided by an air or ground platform. AIR has been developed as both a web service and as a standalone desktop computer application.

The primary research objective of AIR is to "Improve survivability and movement efficiency of air and ground platforms and systems." This highest level objective is met by addressing the following sub-objectives:

- Develop routing technologies that allow avoidance of adverse weather and other obstacles during mission execution.
- Develop technologies that facilitate decision-making for air and ground platform/system movements.

This research results in the following warfighter value/impacts:

- Optimized air and ground movement.
- Decreased friendly force losses and increased mission success rates.
- More efficient use of platforms, weapon systems, and personnel.

Ongoing AIR developments include coordination with:

- AFWA “AFW-WEBS” web services integration.
 - TAIS (PM-Aviation) web services integration.
 - Coalition Attack Guidance Experiment II (CAGEII), which is a networked experiment comprised of modeling and simulation (M&S) systems and tactical systems from multiple countries, including U.S., Canada, U.K., and Australia.
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3. AIR Functionality

AIR is capable of ingesting any data type as a 3D grid of “impacts” to be considered when the application executes. Each cell in the 3D grid is assigned a value which represents a level of severity or “impact” at that particular cell location. One example of such data are areas of adverse weather, or weather impacts. For example, “If windspeed is greater than <some value>, then condition is UNFAVORABLE,” and the “UNFAVORABLE” condition is assigned a value (typically this value is an integer, but not necessarily). My Weather Impacts Decision Aid (MyWIDA), described in section 4, can generate 3D weather impacts grids for various platforms, coupling the operational characteristics of the platform with the weather conditions at every data point in a 3D grid (e.g., forecast data). The resulting 3D grid of impacts can then be fed into AIR, with additional user inputs. A notional example of what a 3D impacts grid may look like is seen as represented in Google Earth in figure 1.

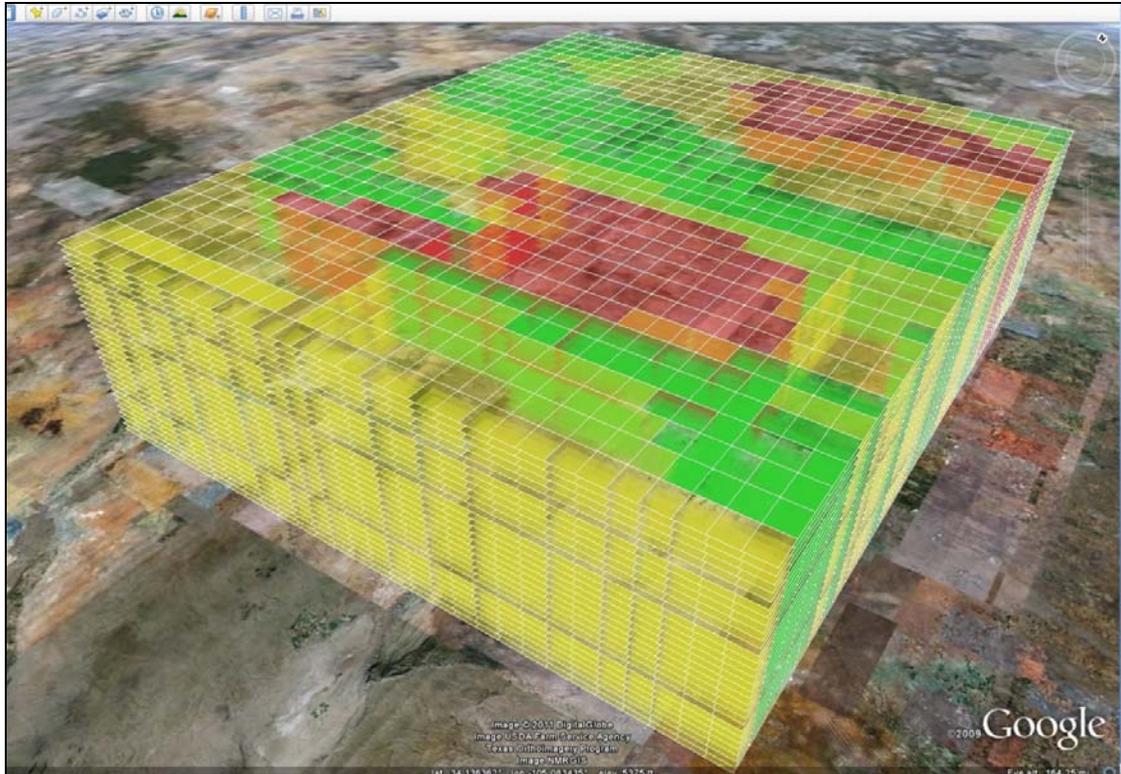


Figure 1. Notional example of a 3D grid of “impacts.” The data from this 30×30×30 grid were used during some of the testing phases of the AIR application.

For best route determination, AIR implements the A* algorithm¹ in 3D space. AIR addresses AWRP deficiencies and adds increased capabilities that were not possible and/or present in AWRP, such as varied airspeeds in different, user-defined route segments, and 3D volume avoidance (e.g., areas of known threat activity, areas of conflicting friendly activity, or other obstacles). The data structures in AIR also lend the application to additional search algorithms, such as D* Lite (Koenig, 2002), the description of which is beyond the scope of this paper.

The AIR implementation of A* is only briefly described in this report. Further details of the A* algorithm are described in Dechter and Pearl (1985). Additionally, improvements to A* are described by Koenig and Likhachev (2005) and Hernandez et al. (2011).

In general, the A* algorithm uses a best-first search and finds a least-cost path from a given “start node” to a “goal node.” It also uses a heuristic, which is an estimate from a node to the goal node, and which allows A* to consider the fewest nodes possible while finding a solution path. The function used in the A* algorithm is as follows:

$$f(n) = g(n) + h(n) \quad (1)$$

¹ A derivative of the A* algorithm has been used by high visibility projects, such as NASA’s Jet Propulsion Laboratory Mars Exploration Rovers “Spirit” and “Opportunity,” as described by Singh (1999).

where

$f(n)$ = the total cost evaluated at the node n

$g(n)$ = the sum of the costs along the current path to the node n from the start node

$h(n)$ = the heuristic function, which is an estimate of the least-cost path remaining between the node n and the goal node

In the AIR implementation of A*, impact costs, described previously, are combined with the traditional movement costs (i.e., costs for distance only to node n) for a total $g(n)$ result. Additionally, while most implementations of A* are describing movement over a single 2D plane (surface movement), the implementation of A* in AIR is executing in 3D space with impacts (and other obstacles) varying over time.

When AIR is executed, either by a web service operation request or directly from an interface in the standalone application, the user request includes 3D-gridded “impacts” data (with or without 3D volumes of avoidance); waypoints required along the path of movement (number of waypoints in the request is not bounded, and only limited by hardware); speed at each waypoint (identifying speed along segment between required waypoints); and the level of “risk” for the resulting path. For the level of risk, there are currently two options: a path of least risk, or a path of higher risk. For the “least risk” option, the impacts data are weighted more heavily, while for the higher risk option, the movement costs are higher than other factors. As an example, if one is willing to traverse higher-risk areas, one can possibly have a shorter path, both spatially and temporally, to arrive at the goal node in a route.

Figure 2 shows AIR output of two paths in Google Earth Keyhole Markup Language (KML) format: high risk and lower risk. The impacts used when the paths were calculated are shown as additional overlays. Though only a single altitude is shown (effectively, a 2D path), this is only shown for visual clarity. In addition, the sample grids shown contain identical impact values for each of the two levels seen. However, AIR has been demonstrated calculating paths through 3D grids, traversing 50 levels of varying 2D impact grids with computation times on the order of 1000 potential paths per second as the final path is calculated. As seen on the left side of the image, each node in the paths contain additional information, such as time at location.

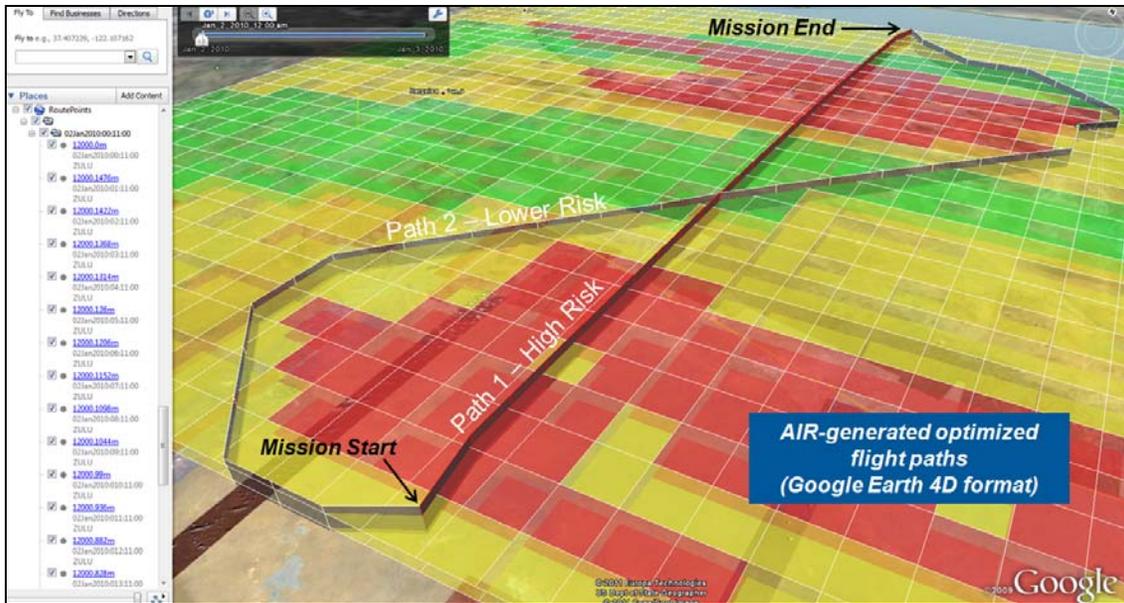


Figure 2. AIR output of two paths in Google Earth KML format: high risk and lower risk. The impacts used when the paths were calculated are shown as additional overlays.

An example of the output from the AIR Java Windows standalone/desktop application (called AIRView) is shown in figure 3.

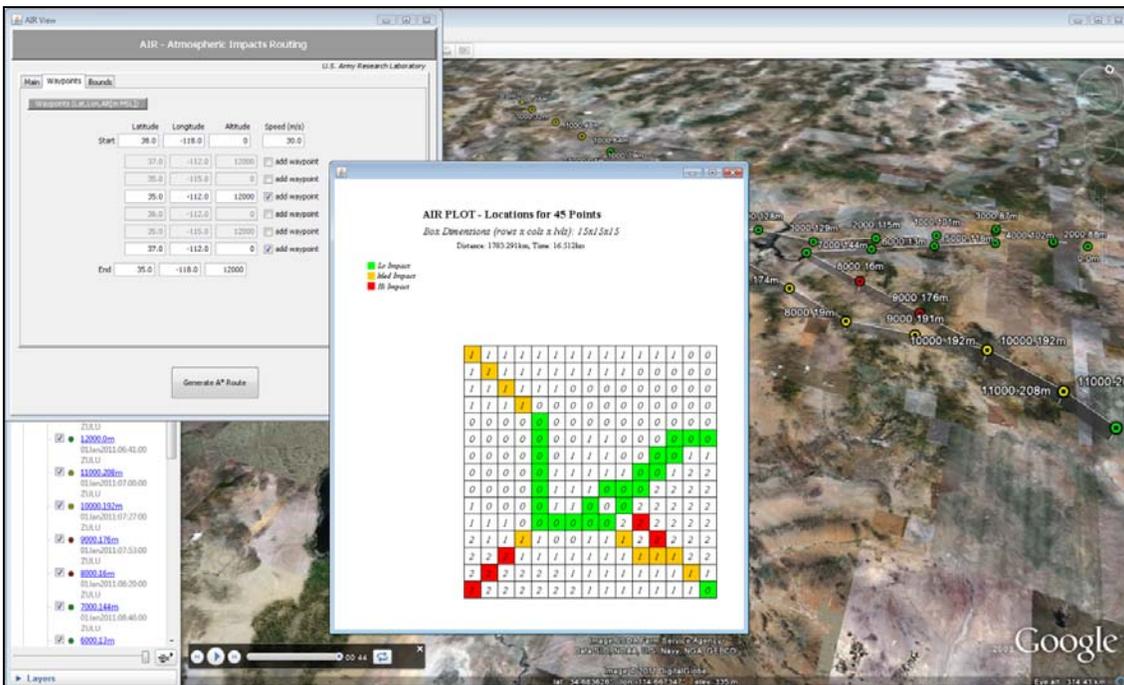


Figure 3. Example output from AIRView (Windows application). Image shows both the Java 2D plot (foreground) and the Google Earth KML output (background).

Figure 3 shows both the Java 2D plot (foreground) as well as the Google Earth KML 4D output (background), both of which were generated simultaneously when AIR was executed. Note that the Java 2D plot shows impact values for the bottom grid layer, only (top-down view), though the path traversed multiple levels.

4. A Source of Weather Impacts for AIR

Regional mesoscale model and nowcast forecast grids supply pertinent data to populate a 4D weather data volume with required raw and post-processed parameters. These forecast data parameters are applied to critical aircraft thresholds such as icing, turbulence, convection, instrument flight rules (IFR) conditions, winds, crosswinds, etc., along a flight path. When critical weather thresholds are identified, the specific points are labeled to show favorable, marginal, and unfavorable (or adverse) hazardous flight weather, depending on the exceeded threshold. Thus, a tailored weather effects field is created for each aircraft based on the aircraft's specific weather sensitivity thresholds (Knapp et al., 2006).

MyWIDA, developed by ARL's Battlefield Environment Division as part of the Tri-Service Integrated Weather Effects Decision Aid (T-IWEDA) program, is a tactical decision aid for automating the prediction and display of forecast weather impacts on military systems and operations based on live data acquisition and user-defined critical thresholds in conjunction with customized databases of thresholds/impacts.

A prototype of the MyWIDA Version 2 web service application reference client is shown in figure 4.

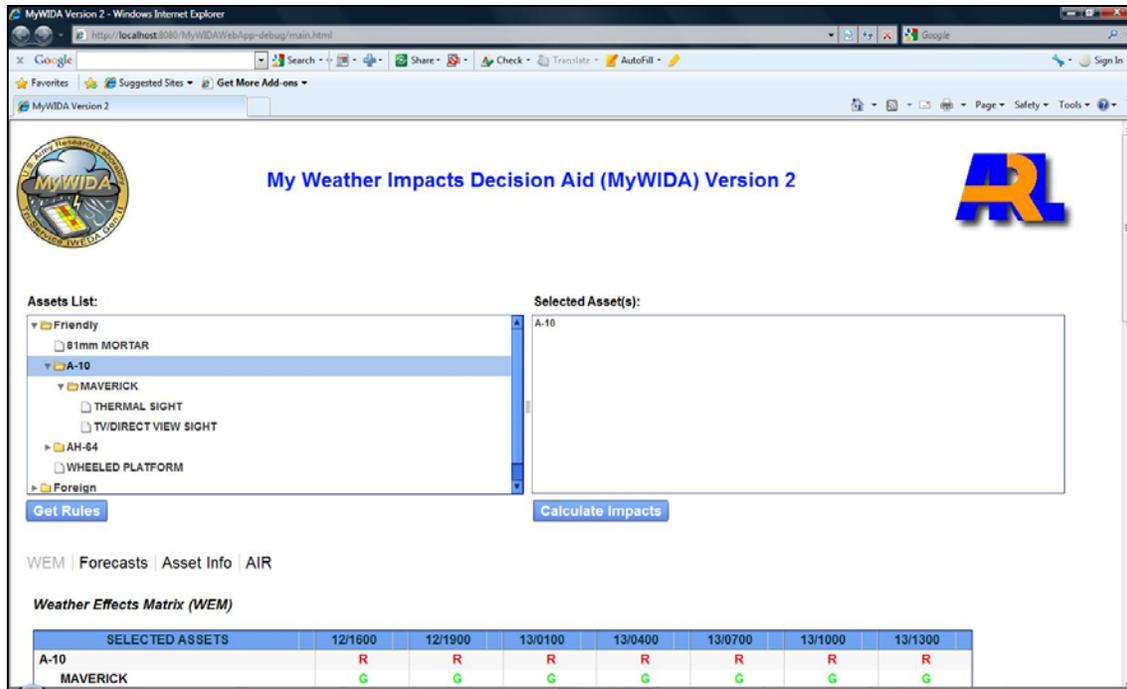


Figure 4. Prototype MyWIDA Version 2 reference graphical user interface.

5. Conclusions

Alternative routing options that consider environmental factors along a planned path of movement are of high importance during combat operations. Such environmental conditions may consist of adverse weather, areas of known threat, areas of conflicting friendly activity, or other obstacles.

Designed and developed from scratch, the AIR application allows the determination of a least-cost path across multiple waypoints and will determine this path based on a 3D grid of impacts, regardless of the impact type. Additionally, AIR provides a mechanism to identify 3D volumes to avoid when calculating a path, allowing identification of exclusion zones due to buildings, terrain, friendly/threat operations, or other user-defined conditions. Due to its design, AIR is a highly-flexible and efficient route planning software package applicable to multiple domains, including both air and surface operations, and may be executed either as a standalone desktop application or deployed as a web service.

6. References

- Knapp, D.; Raby, J.; Measure, E.; Brown, R.; Gupta, V. A weather decision aid for unmanned aerial vehicle missions. *Twelfth Conf. on Aviation, Range, and Aerospace Meteorology*, Atlanta, GA . Amer. Meteor. Soc., [Online] **2006**.
- Singh, S. The Mars Autonomy Project. <http://www.frc.ri.cmu.edu/projects/mars/>(accessed 2010).
- Koenig, S.; Likhachev, M. D* Lite. *American Association for Artificial Intelligence (AAAI)*, [Online] **2002**, 476–483.
- Dechter, R.; Pearl, J. Generalized Best-First Search Strategies and the Optimality of A*. *Journal of the Association of Computing Machinery* **1985**, 32, (3), 505–536.
- Koenig, S.; Likhachev M. Adaptive A*. *4th International Joint Conference on Autonomous Agents and Multiagent Systems*, Utrecht, Netherlands, July 25–29, 2005.
- Hernandez, C.; Sun, X.; Koenig, S.; Meseguer, P. Tree Adaptive A*. *Proceedings of the International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS)*, Taipei, Taiwan, May 2–6, 2011.

Bibliography

Patel, A.J. Amit's thoughts on path-finding and A-Star.

<http://theory.stanford.edu/~amitp/GameProgramming/>(accessed 2010).

List of Symbols, Abbreviations, and Acronyms

AFWA	U.S. Air Force Weather Agency
AFW-WEBS	Air Force Weather Web Services
AIR	Atmospheric Impacts Routing
ARL	U.S. Army Research Laboratory
AWRT	Aviation Weather Routing Tool
CAGEII	Coalition Attack Guidance Experiment II
IFR	Instrument flight rules
KML	Keyhole Markup Language
M&S	modeling and simulation
MyWIDA	My Weather Impacts Decision Aid
TAIS	Tactical Airspace Integration System
T-IWEDA	Tri-Service Integrated Weather Effects Decision Aid

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