14.2 Weather impacts and routing services in support of airspace management operations

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1. Introduction

Atmospheric impacts on platforms and alternative routing options which consider environmental factors along a planned path of movement are of high importance to military aviation and similarly for the civilian community. Such options serve to improve movement efficiency of aircraft and ensure the safety of airframes, on-board personnel and passengers. Environmental factors which may adversely affect aircraft systems along a projected path include adverse weather, terrain, restricted airspace, conflicting aviation corridors, and other obstacles. The U.S. Army Research Laboratory's Battlefield Environment Division is developing web services which generate grids of atmospheric impacts on aircraft platforms as well as services which calculate optimized routes in 3D space, avoiding adverse atmospheric conditions and other obstacles during mission execution. ARL's web services will supplement the Army's airspace management system called the Tactical Airspace Integration System (TAIS). ARL's web service technologies will mesh with and incorporate TAIS airspace conflict detection services as input for route optimization.

2. Weather Impacts Services: My Weather Impacts Decision Aid (MyWIDA)

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, 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).

The My Weather Impacts Decision Aid (MyWIDA), developed by the U.S. Army Research Laboratory's Battlefield Environment Division as part of the Tri-Service Integrated Weather Effects Decision Aid (T-IWEDA) program, is a PC/Windows 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

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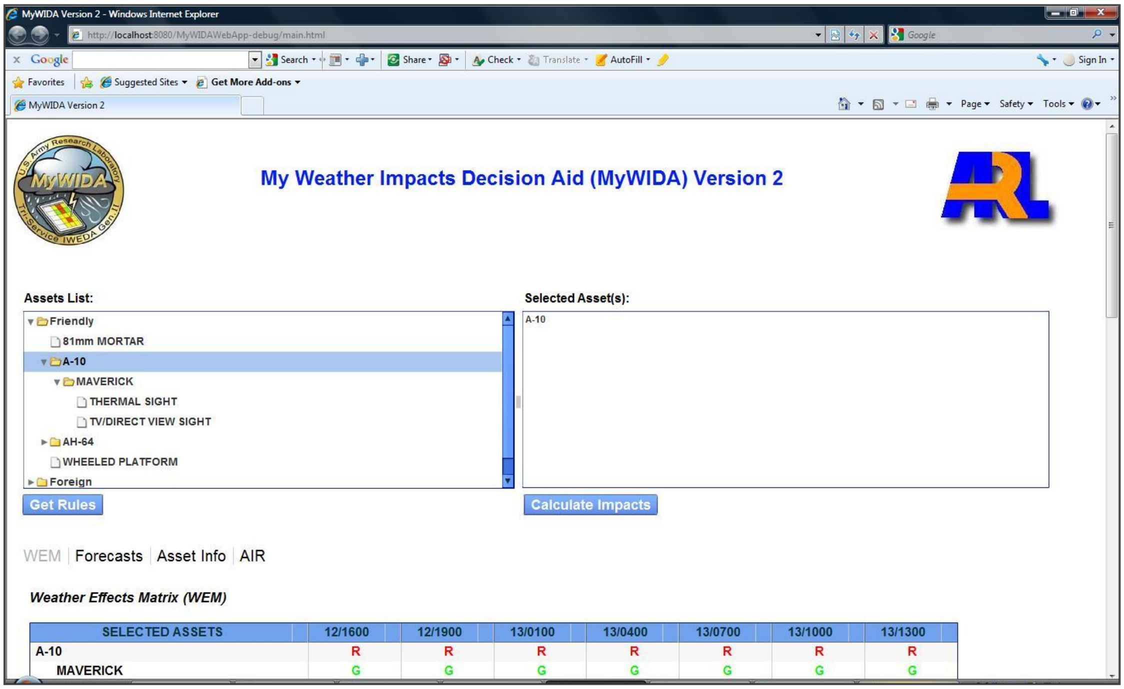
customized databases of thresholds/impacts. MyWIDA is a next generation technology product using accredited components that satisfies key Army weather requirements. MyWIDA graphical output includes displays of color-coded weather impacts overlayed across a 2-D map domain (not shown) and color-coded Weather Effects Matrix displays showing time-phased weather impacts valid at a selected point on the map display. A prototype of the MyWIDA Version 2 web service application reference client is shown in Figure 1, below.



My Weather Impacts Decision Aid (MyWIDA) Version 2

Assets List:

- Friendly
  - 81mm MORTAR
  - A-10
    - MAVERICK
      - THERMAL SIGHT
      - TV/DIRECT VIEW SIGHT
  - AH-64
  - WHEELED PLATFORM
- Foreign

Selected Asset(s):

A-10

Weather Effects Matrix (WEM)

SELECTED ASSETS	12/1600	12/1900	13/0100	13/0400	13/0700	13/1000	13/1300
A-10	R	R	R	R	R	R	R
MAVERICK	G	G	G	G	G	G	G

Figure 1. Prototype MyWIDA Version 2 reference Graphical User Interface.

3. Routing Service: Atmospheric Impacts Routing (AIR)

The Atmospheric Impacts Routing (AIR) application is a replacement to the Army’s earlier Aviation Weather Routing Tool (AWRT) described by Knapp, et.al. 2008. The implementation of AIR allows it to be applied to air and ground routing applications by its use of 4D data grids (3-dimensional 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.

The primary research objective of AIR for aviation applications is to improve survivability and movement efficiency of aircraft across a given airspace domain. This highest level objective is met by addressing the following sub-objectives:

- Develop routing technologies which allow avoidance of adverse weather and other obstacles during aircraft mission execution.

- Develop technologies which facilitate decision-making for aircraft movements.

This research results in the following positive impacts:

- Optimized aircraft movement through airspace domains.
- Increased aircraft flight performance and flight mission success rates.
- More efficient use of airspace, aircraft, and personnel.

AIR can take in *any* data type as a 3D grid of "impacts." One such data type is weather impacts: For example, "If wind speed is greater than <some value>, condition is UNFAVORABLE." MyWIDA, described in the previous section, can generate 3D weather impacts grids for various aircraft, coupling the operational aircraft characteristics 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.

For best route determination, AIR implements the A* algorithm[1] in 3D space. AIR addresses AWRT deficiencies, and adds increased capabilities which were not possible and/or present in AWRT, such as varied airspeeds in different, user-defined route segments, and 3D volume avoidance (e.g., restricted airspace or other obstacles). The data structures in AIR also lend the application to additional search algorithms, such as D* Lite, the description of which is beyond the scope of this paper.

The AIR implementation of A* is described here only briefly. Further details of the A* algorithm, including recent improvements, are described by 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:

$$f(n) = g(n) + h(n)$$

Where $f(n)$ is the total cost at the current node n, $g(n)$ is the sum of the costs along the current path from the start node, and $h(n)$ is a cost estimate of the least-cost path remaining between the current node n and the goal node.

In the AIR implementation of A*, impact costs, described previously, are combined with the traditional movement costs 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

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[1] A derivative of the A* algorithm has been used by high visibility projects such as NASA's JPL Mars Exploration Rovers "Spirit" and "Opportunity."

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 KML format: Low risk, and high 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 in Fig 2 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 Fig 2, each node in the paths contains additional information, such as time and altitude.

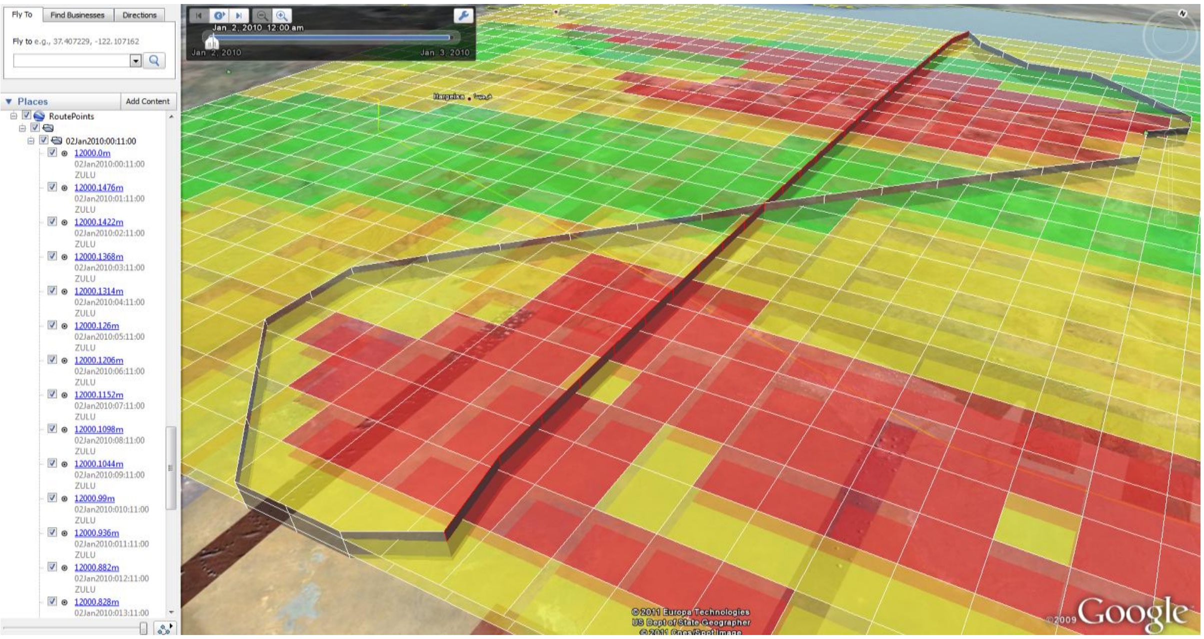
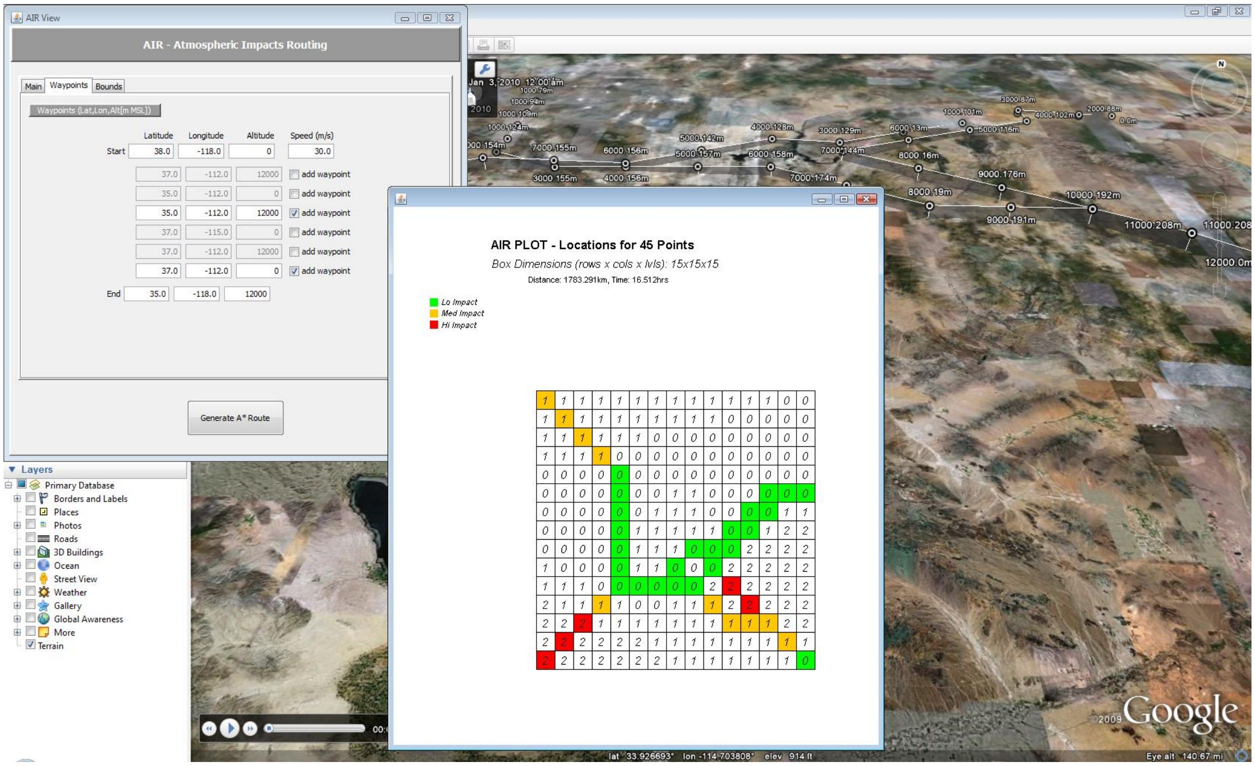


Figure 2. AIR output of two paths in Google Earth KML format: Low risk (longer curved path), and high risk (shorter straight path). The impacts used when the paths were calculated are shown as additional overlays.

An example of the output from the AIR Java Windows standalone application (called AIRView) is shown in Figure 3, below. The figure 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.



	Latitude	Longitude	Altitude	Speed (m/s)
Start	38.0	-118.0	0	30.0
	37.0	-112.0	12000	☐ add waypoint
	35.0	-112.0	0	☐ add waypoint
	35.0	-112.0	12000	☑ add waypoint
	37.0	-115.0	0	☐ add waypoint
	37.0	-112.0	12000	☐ add waypoint
	37.0	-112.0	0	☑ add waypoint
End	35.0	-118.0	12000	

AIR PLOT - Locations for 45 Points

Box Dimensions (rows x cols x lvls): 15x15x15

Distance: 1783.291km, Time: 16.512hrs

🟩 *Lo Impact*
🟧 *Med Impact*
🟥 *Hi Impact*

1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
0	0	0	0	0	0	1	1	1	0	0	0	0	1	1
0	0	0	0	0	1	1	1	1	1	0	0	1	2	2
0	0	0	0	0	1	1	1	0	0	0	2	2	2	2
1	0	0	0	0	1	1	0	0	0	2	2	2	2	2
1	1	1	0	0	0	0	0	0	2	2	2	2	2	2
2	1	1	1	1	0	0	1	1	1	2	2	2	2	2
2	2	2	1	1	1	1	1	1	1	1	1	1	2	2
2	2	2	2	2	2	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	1	1	1	1	1	1	1	0

lat 33.926693° lon -114.703808° elev 914 ft

Figure 3. Example output from AIRView (Windows application), showing both the Java 2D plot (foreground) as well as the Google Earth KML output (background).

4. TAIS, MyWIDA, and AIR Interoperation

The projected interoperation of the TAIS web services with AIR and MyWIDA are shown in Figure 4. The initial service request is generated from the TAIS web services, which selects an asset or list of assets (aircraft and any subsystems) for some area of interest and timeframe. MyWIDA then couples aircraft-specific operational characteristics (which are in the form of rules, such as, “If wind speed is greater than <some value>, condition is UNFAVORABLE”) with the forecast data for the location/time. MyWIDA then sends a 4D (3D grids for different forecast times) “weather impacts” grid to TAIS. TAIS then adds any “conflict areas” (as 3D volumes) coupled with the 4D weather impacts grid, a list of required waypoints to move through, and other conditions (described earlier in this paper) as a request to AIR. AIR takes the input, and calculates a best path through the waypoints with the given conditions, returning a Google Earth KML route with time at location information.

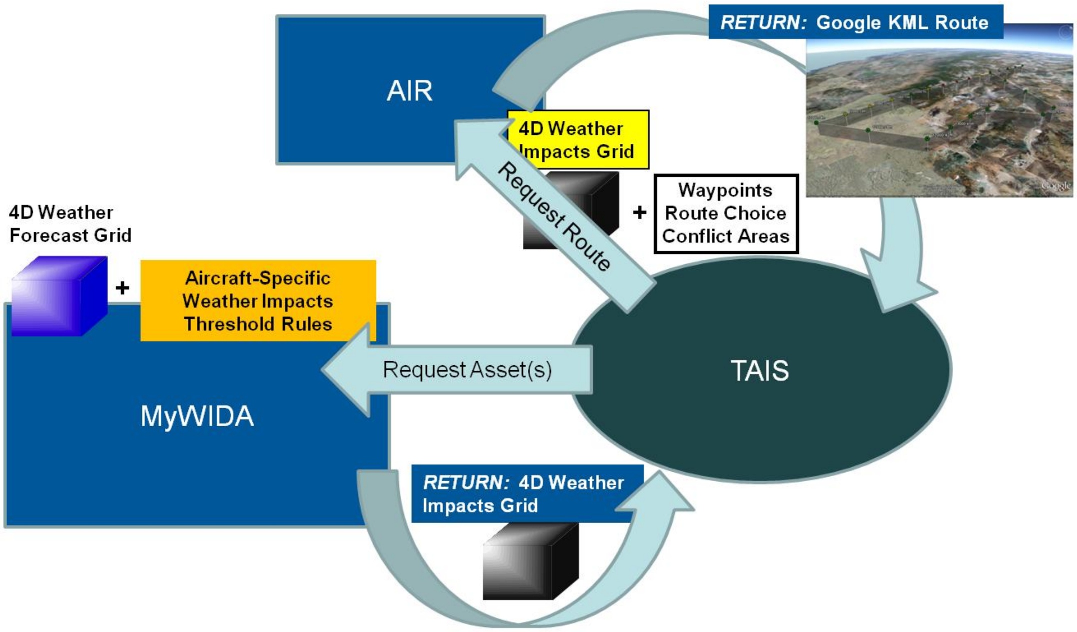


Figure 4. Projected interoperation of the TAIS web services with MyWIDA and AIR.

5. Conclusion

Scientists at Army Research Laboratory have developed aircraft routing technologies and route optimization capabilities which focus on weather impacts and other airspace considerations added to flight route mission planning and enroute decision making. The flight route optimization takes into account predicted and current weather impacts plus non-weather airspace restrictions. These technologies are being integrated into the U.S. Army's Tactical Airspace Integration System, used for battlefield aircraft and airspace management by tactical air controllers. The aircraft routing and optimization technologies are suitable for comparable non-military airspace management use in managing and routing aircraft through civilian airspace and aviation corridors.

6. References

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