



Aviation Weather Routing Tool: A Decision Aid for Manned/Unmanned Aircraft Routing



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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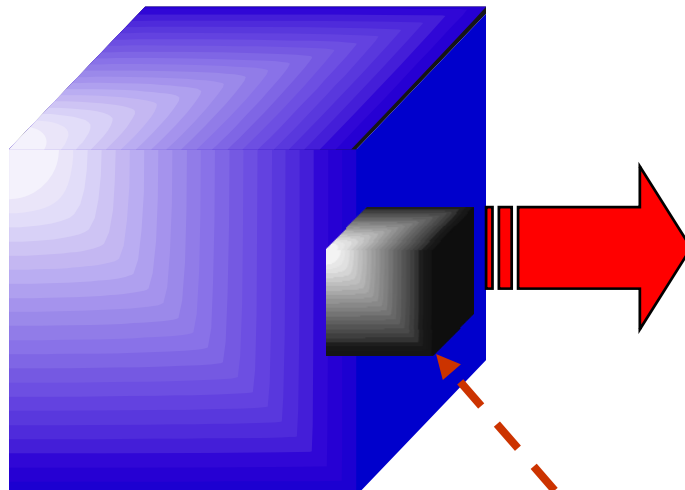
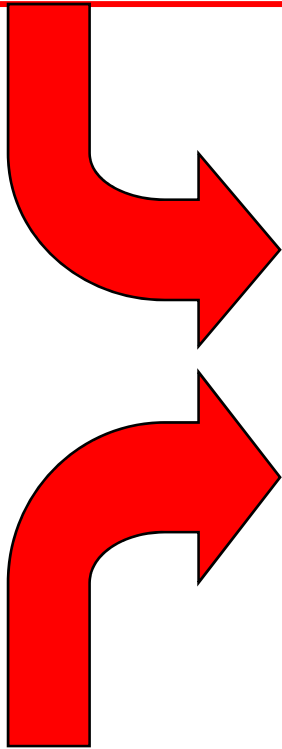
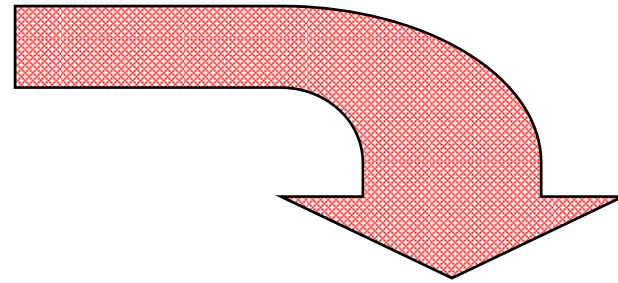
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GENERAL SUPPORT CONCEPT



Theater-scale forecast model database...
“Weather Data Cube”
→ 4-D gridded fields of weather parameters



Weather Decision
Aid Products for manual and
automated applications.

Nesting → Nowcast 0-3hr Database.
Automated refresh of forecast 4-D
cube for pre-mission & enroute updates.

LOCAL SENSORS
Surface Data Sensors
Upper-Air Sensors
Aircraft MET Sensors

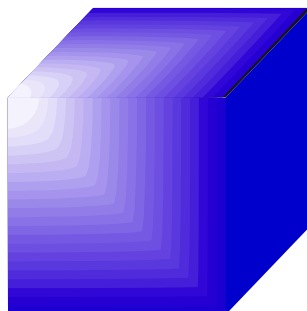
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“Optimized” Flight Path Aviation Weather Routing Tool (AWRT)



New 4-D Weather
Forecast Grid



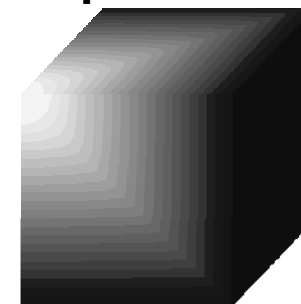
+

**Aircraft-Specific
Weather Impacts
Threshold Rules**

*(from Tri-Service
Integrated Weather
Effects Decision Aid (T-
IWEDA) database)*

=

4-D Weather
Impacts Grid



+

Altered Flt Path (if needed)

**Initial/Current
Flight Path**

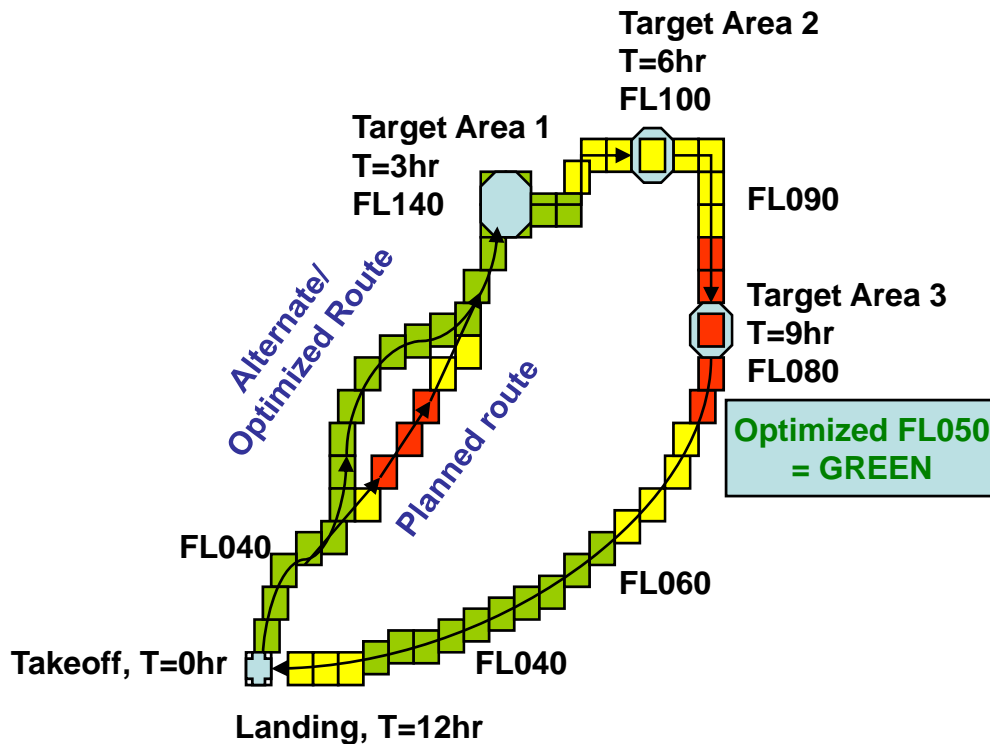
**New Flt Path Options;
Avoiding Enrte Hazards**

**PATH
OPTIMIZATION**

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“Optimized” Flight Path Aviation Weather Routing Tool (AWRT)



- **Original planned flight path routes through “red” or “unfavorable” conditions**
- **Automated flight route optimization algorithms to provide alternate routes around, over, under unfavorable conditions**
- **Look for the “greenest” or “most favorable” path**
- **Solution is an “all-weather” routing option to increase mission success rates.**
- **Technology applicable to ALL aircraft**



AWRT Development: Adapting the A* Routing Algorithm



- **Computes the “Lowest Cost” path between points.**
- **Cost function can represent fuel consumption, hazard to the aircraft, mission constraints, etc.**
- **Searches out from a starting point, storing partial paths after each step.**
- **The partial paths are stored in a prioritized list.**
- **A Cost Function then determines the “Lowest Cost” of the paths in the priority list.**
- **A* is guaranteed to find a lowest cost path and is usually computationally cheaper than an exhaustive (or breadth first) search.**



A* on a 2-D Grid



A* Demonstration - Microsoft Internet Explorer

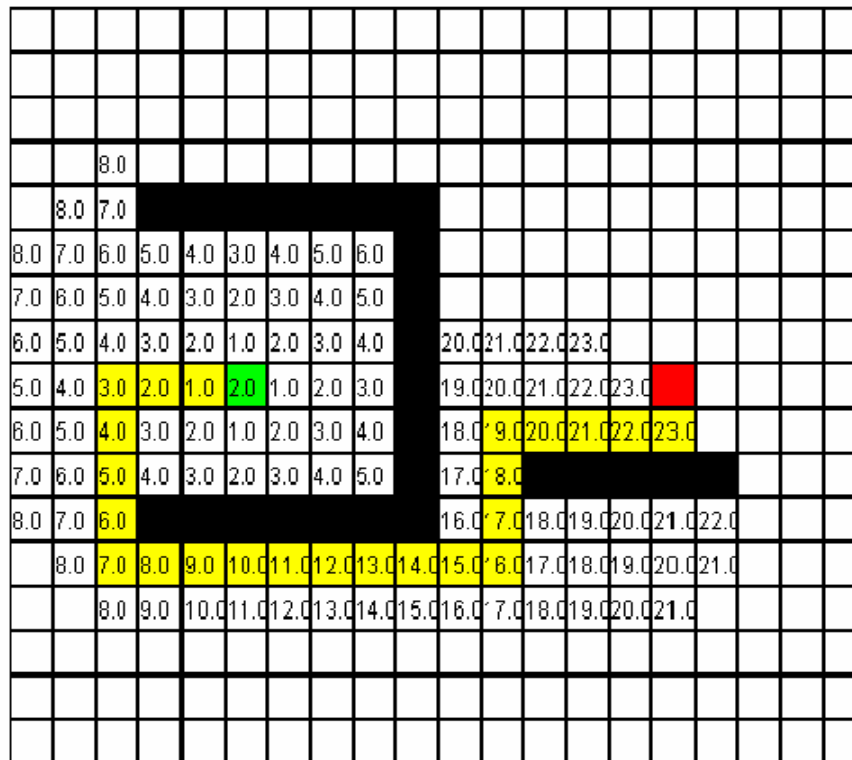
File Edit View Favorites Tools Help



Address <http://www.vision.ee.ethz.ch/~buc/astar/AStar.html>

A* Demonstration

Load Map: Method:



set blocks

Impossible

set start

set finish

30

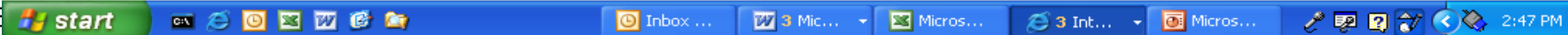
Key

- Start Point
- End Point
- Tough
- V.Tough
- Impossible
- Easy
- Route

The numbered squares are the searched squares with the costs to reach them. The yellow path is the "least cost" path.

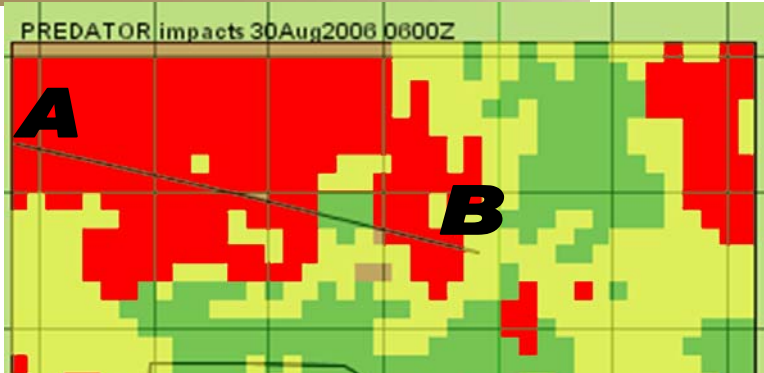
Applet AStarApplet started

Internet



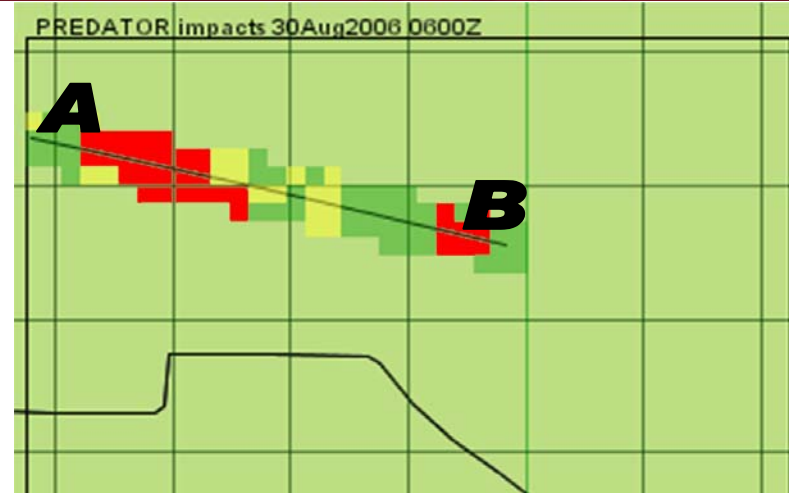


Applying A* to Flight Route Optimization

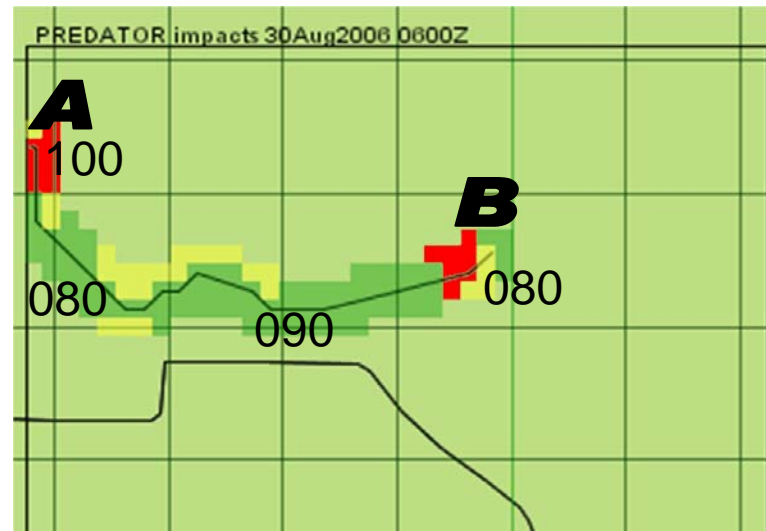


Worst conditions shown for all altitudes

Planned route from A to B at FL100 passes through unfavorable conditions



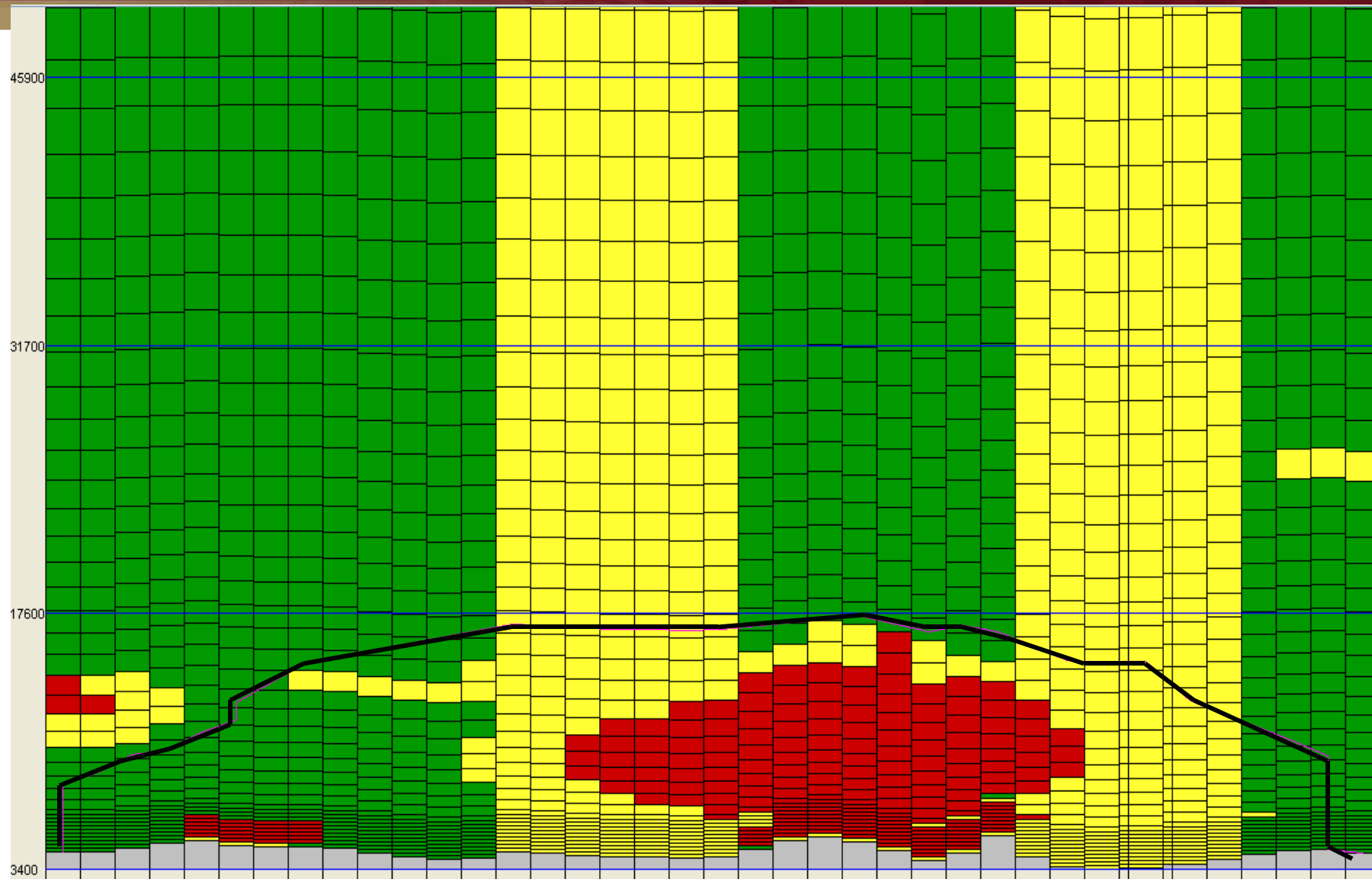
Worst Conditions at FL100 (+/- 500')



Optimized route at varying FLs



Optimized Vertical Slice

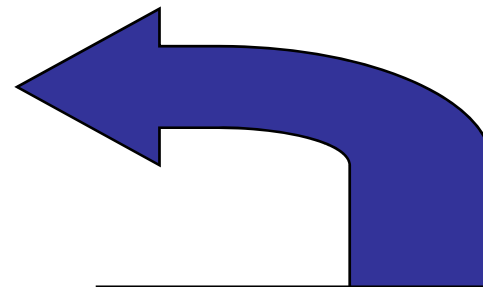




1. Web-Enabled/Net-Centric (Thin Client)

AWRT Server – access to 4-D Weather data cube:

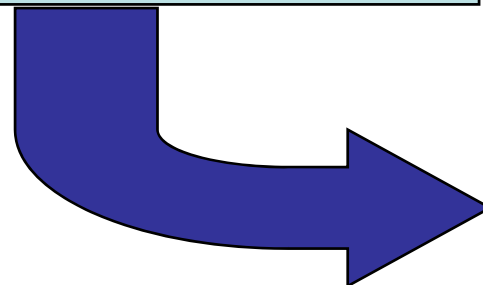
1. **Receives route request**
2. **Calculates weather effects data cube based on aircraft & restrictions**
3. **Meshes route with weather effects data cube**
4. **Derives initial weather effects on route**
5. **Calculates AWRT optimized route options**
6. **Creates display and A/N output of route options**
7. **Data and display available to Operator/Planner/GCS/M2M to Aircraft**



Via web page interface, enter:
-Aircraft info
-Route waypoints & altitudes
-Enter restrictions
-Send request



Operator/Planner/GCS:
PC/Laptop with
SIPRNET/NIPRNET connectivity



TEC



2. Autonomous (Local) Capability (Thick Client)

Operator/Planner/JMPS/GCS/??:

Server/PC/Laptop hosts

1. Comm. connectivity to ingest 4-D Weather Grids
2. Weather Effects Grid Creator
3. AWRT Route Optimization capability
4. A/N & graphics output of route options

4-D Weather Forecast Data Cube:
DCGS-A Weather
Regional/Theater Forecast Center
AF Weather Agency

- Calculates weather effects data cube based on aircraft & restrictions
- Meshes route with weather effects data cube
- Derives initial weather effects on route
- Calculates AWRT optimized route options
- Creates local display and A/N output of route options/M2M to Aircraft



AWRT DEMO



Select Asset(s) from List:



The screenshot displays the Tri-Service IWEDA software interface. The main window is titled "Tri-Service IWEDA" and contains several panes:

- List Pane:** A tree view of asset categories. "Scan Eagle UAS" is highlighted in blue. A red callout box labeled "Available Asset List" points to this pane.
- Selected Assets Pane:** Shows "Scan Eagle UAS" as the selected asset. A red callout box labeled "User Selected Asset List (ScanEagle UAS)" points to this pane.
- Map Pane:** A topographic map of the Phoenix, Arizona area with various flight paths and assets overlaid. A red callout box labeled "Available Forecast Times (all selected)" points to the "Forecasts" pane.
- Forecasts Pane:** A list of forecast times from 180ct2007 0000Z to 190ct2007 1800Z. All items are selected, indicated by a blue background. A "Select All" button is visible.
- Buttons:** "Add", "WEM", and "Save" buttons are located below the List pane.



Compute Weather Effects Matrix:



Tri-Service IWEDA

File Edit Screen Help

List Hierarchy Selected

- SOF AIRDROP/EQUIP
- SOF AWADS
- SOF CAS
- SOF COMM
- SOF EO/IR
- SOF GROUND
- SOF HELO
- SOF MARITIME
- SOF MFF
- SOF NBC
- SOF PSYOPS
- SOF RECON/SURV
- SOF STEERABLE/CHUTE
- STINGER-AIRBORNE
- STINGER-GROUND

No special condition

Selected Assets

- Scan Eagle UAS

Map Asset Info Impact Levels

1:2,250,000

Geospatial Area of Interest (AOI):

Compute Weather Effects Matrix (WEM) button

Add WEM Save

Forecasts Subdomains

- Planning
 - 18Oct2007 0000Z
 - 18Oct2007 0300Z
 - 18Oct2007 0600Z
 - 18Oct2007 0900Z
 - 18Oct2007 1200Z
 - 18Oct2007 1500Z
 - 18Oct2007 1800Z
 - 18Oct2007 2100Z
- Current Ops
 - 19Oct2007 0000Z
 - 19Oct2007 0300Z
 - 19Oct2007 0600Z
 - 19Oct2007 0900Z
 - 19Oct2007 1200Z
 - 19Oct2007 1500Z
 - 19Oct2007 1800Z

Select All Deselect All Recenter Refresh

Lat, Lon (32.407, -115.35) - x, y (3,638)

ScanEagle color coded WEM over forecast times (red=unfavorable, amber=marginal impacts)

Name	18/0000	18/0300	18/0600	18/0900	18/1200	18/1500	18/1800	18/2100	19/0000	19/0300
Selected Assets	R	R	R	R	R	R	R	R	R	R
Scan Eagle UAS	R	R	R	R	R	R	R	R	R	R



View ScanEagle Impacts over AOI:



Tri-Service IWEDA

File Edit Screen Help

List Hierarchy Selected

No special condition

Selected Assets

- Scan Eagle UAS

Map Asset Info Impact Levels

1:2,250,000

Geospatial impacts at 1200 GMT on the 18th

Lat, Lon (34.338, -112.269) - x, y (772,1)

Name	18/0000	18/0300	18/0600	18/0900	18/1200	18/1500	18/1800	18/2100	19/0000	19/0300
Selected Assets	R	R	R	R	R	R	R	R	R	R
Scan Eagle UAS	R	R	R	R	R	R	R	R	R	R

Forecasts Subdomains

Planning

Current Ops

- 18Oct2007 0000Z
- 18Oct2007 0300Z
- 18Oct2007 0600Z
- 18Oct2007 0900Z
- 18Oct2007 1200Z
- 18Oct2007 1500Z
- 18Oct2007 1800Z
- 18Oct2007 2100Z
- 19Oct2007 0000Z
- 19Oct2007 0300Z
- 19Oct2007 0600Z
- 19Oct2007 0900Z
- 19Oct2007 1200Z
- 19Oct2007 1500Z
- 19Oct2007 1800Z

Select All

Deselect All

Recenter

Refresh

Add WEM Save



Define the Flight Path (FP):



Subdomain Name: ScanEagle2

Border Color: [Black]

Area: Assets

Takeoff/Way Points

Lat:	32.707	Alt:	<input type="checkbox"/> All	feet
Lon:	-114.657			
Lat:	33.459	Alt:	<input type="checkbox"/> All	feet
Lon:	-112.814			

Buttons: Stop Map Input, Clear, Commit, Cancel

Map Labels: Begin, End

Map Coordinates: Lat, Lon (33.135, -113.146) - x, y (553,451)

Map Scale: 1:2,250,000

Map Assets: WEM, Impacts

Map Legend: AGL, MSL, Time Sensitive

Waypoints/times are entered via map clicks (or manually) – M2M in future release



Compute & View Impacts over FP:



Tri-Service IWEDA

File Edit Screen Help

Map Route Planning Impact Levels

1:2,250,000

Numerous adverse impacts along FP:

Impacts include turbulence & high winds aloft

Selected Assets

- Scan Eagle UAS
 - Rules of Scan Eagle UAS
 - Light Turbulence
 - turbulenceintensity = light
 - heightmsl < 16000.0 feet
 - Moderate or greater turbulence
 - heightmsl < 16000.0 feet
 - turbulenceintensity >= moderate
 - Moderate winds aloft
 - upperairwindspeed > 25.0 knots
 - heightmsl < 16000.0 feet
 - Strong winds aloft
 - upperairwindspeed > 35.0 knots
 - heightmsl < 16000.0 feet

Subdomains

- Predator (optimized)
- Predator (optimized)[1]
- Predator
- ScanEagle1
- ScanEagle2 (optimized)
- ScanEagle2

Name	18/0000	18/0300	18/0600	18/0900	18/1200	18/1500	18/1800	18/2100	19/0000	19/0300	19/0600
Selected Assets	R	R	R	R	R	R	R	R	R	R	R
Scan Eagle UAS	R	R	R	R	R	R	R	R	R	R	R

Lat, Lon (33.832, -113.088) - x, y (566,135)

start C:\Docu... webapps iwedaop... Java EE ... WINR_Y... Tri-Servi... ScanEagl... Type to s... 3:42 PM



Flight Slice along Path:



Tri-Service IWEDA

File Edit Screen Help

List Selected

No special condition

Selected Assets

- Scan Eagle UAS
 - Rules of Scan Eagle UAS
 - Light Turbulence
 - turbulenceintensity = light
 - heightmsl < 16000.0 feet
 - Moderate or greater turbulence
 - heightmsl < 16000.0 feet
 - turbulenceintensity >= moderate
 - Moderate winds aloft
 - upperairwindspeed > 25.0 knots
 - heightmsl < 16000.0 feet
 - Strong winds aloft
 - upperairwindspeed > 35.0 knots
 - heightmsl < 16000.0 feet

Map Route Planning Impact Levels

Flight slice shows impacts at many levels – need to run the Route Optimizer!

Lat: 33.53
Lon: -112.75
Height AGL: 9997 feet
Height MSL: 11329 feet

Forecasts Subdomains

New Subdomain

Select All

Deselect All

- Predator (optimized)
- Predator (optimized)[1]
- Predator
- ScanEagle1
- ScanEagle2 (optimized)
- ScanEagle2

Name	18/0000	18/0300	18/0600	18/0900	18/1200	18/1500	18/1800	18/2100	19/0000	19/0300	19/0600
Selected Assets	R	R	R	R	R	R	R	R	R	R	R
Scan Eagle UAS	R	R	R	R	R	R	R	R	R	R	R

WEM Impacts

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Route Planning Specifics:



Tri-Service IWEDA

File Edit Screen Help

List Selected Map Asset Info Route Planning Impact Levels

Route Planning

No special condition

Selected Assets

- Scan Eagle UAS
- Rules of Scan Eagle UAS
 - Light Turbulence
 - turbulenceintensity = light
 - heightmsl < 16000.0 feet
 - Moderate or greater turbuler
 - heightmsl < 16000.0 feet
 - turbulenceintensity >= m
 - Moderate winds aloft
 - upperairwindspeed > 25.0
 - heightmsl < 16000.0 feet
 - Strong winds aloft
 - upperairwindspeed
 - heightmsl < 16000.0

Low 0 1000 2000 3000 4000 5000 0 Feet MSL AGL -Very Risky

High 0 1000 2000 3000 4000 5000 16,000 Feet MSL AGL -Risky

Beginning Time 18 October 2007 11 00

Speed 100 Knots

Execute

Forecasts Subdomains

New Subdomain Select All Deselect All

- Predator (optimized)
- Predator (optimized)[1]
- Predator
- ScanEagle1
- ScanEagle2 (optimized)
- ScanEagle2

WEM Impacts

Name	18/0000	18/0300	18/0600	18/0900	18/1200	18/1500	18/1800	18/2100	19/0000	19/0300
Selected Assets	R	R	R	R	R	R	R	R	R	R
Scan Eagle UAS	R	R	R	R	R	R	R	R	R	R

ScanEagle max ceiling and speed along with begin time and risk tolerance are set here



Optimized FP Results:



Optimized flight path waypoints & times are viewable:

Optimized route avoids all adverse weather!

Tri-Service IWEDA

File Edit Screen Help

List Selected Map Route Planning Impact Levels

No special condition 1:2,250,000

Edit Subdomain "ScanEagle2 (optimized)"

Subdomain Name ScanEagle2 (optimized)

Get From Map Clear

Lat: 32.759	Alt: <input checked="" type="checkbox"/> 295.276	feet
Lon: -114.611		
Lat: 32.726	Alt: <input checked="" type="checkbox"/> 770.672	feet
Lon: -114.039		
Lat: 32.726	Alt: <input checked="" type="checkbox"/> 961.739	feet
Lon: -113.877		
Lat: 32.996	Alt: <input checked="" type="checkbox"/> 1,417.516	feet
Lon: -113.554		
Lat: 33.131	Alt: <input checked="" type="checkbox"/> 1,464.675	feet
Lon: -113.393		
Lat: 33.131	Alt: <input checked="" type="checkbox"/> 1,562.648	feet
Lon: -113.232		
Lat: 33.4	Alt: <input checked="" type="checkbox"/> 1,366.165	feet
Lon: -112.909		
Lat: 33.51	Alt: <input checked="" type="checkbox"/> 1,332.021	feet
Lon: -112.82		

AGL MSL

Time Sensitive

Commit Cancel

3.837 - x, y (379,0)

Name	18/0000	18/0300	18/0600	18/0900	18/1200	18/1500	18/1800	18/2100	19/0000	19/0300	19/0600
Selected Assets	X	X	X	X	A	X	X	X	X	X	X
Scan Eagle UAS	X	X	X	X	A	X	X	X	X	X	X

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Flight Slice along Optimized Path:



Tri-Service IWEDA

File Edit Screen Help

List Selected

No special condition

Selected Assets

- Scan Eagle UAS
 - Rules of Scan Eagle UAS
 - Light Turbulence
 - turbulenceintensity = light
 - heightmsl < 16000.0 feet
 - Moderate or greater turbulence
 - heightmsl < 16000.0 feet
 - turbulenceintensity >= moderate
 - Moderate winds aloft
 - upperairwindspeed > 25.0 knots
 - heightmsl < 16000.0 feet
 - Strong winds aloft
 - upperairwindspeed > 35.0 knots
 - heightmsl < 16000.0 feet

Map Route Planning Impact Levels

44900
37500
30000
22600
15200
7700
300

Optimized Flight Slice shows no adverse impacts!

Forecasts Subdomains

New Subdomain Select All Deselect All

- Predator (optimized)
- Predator (optimized)[1]
- Predator
- ScanEagle1
- ScanEagle2 (optimized)
- ScanEagle2

WEM Impacts

Name	18/0000	18/0300	18/0600	18/0900	18/1200	18/1500	18/1800	18/2100	19/0000	19/0300	19/0600
Selected Assets	X	X	X	X	A	X	X	X	X	X	X
Scan Eagle UAS	X	X	X	X	A	X	X	X	X	X	X

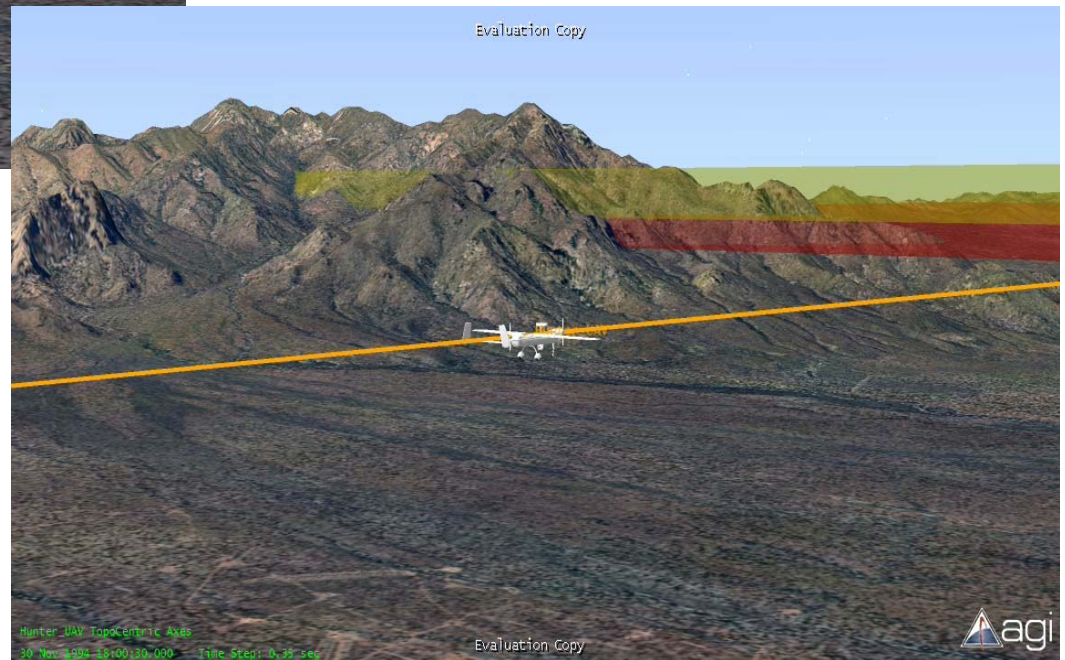
start C:\Docu... webapps iwedaop... Java EE ... WINR_Y... Tri-Servi... ScanEagl... Type to s... 3:39 PM



AWRT Visualization: Satellite Took Kit (STK) Visualization Software



UAS flight through unfavorable weather conditions (depicted in red) such as Severe Turbulence



Optimized flight route, automatically routed UNDER the hazardous weather levels.

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



CAPABILITIES: Current and Future



CURRENT:

- PC-based & IMETS/DCGS-A Hosted
- Hard-wired to T-IWEDA
- Map GUI = Open Map
- User input of route and flight levels
- Routing rules (cost functions) include:
 - Weather hazards
 - Air speed
 - Head wind component
 - Forecast periods corresponding to flight times

FUTURE:

- Browser version
- Platform independent
- JAAWIN-hosted (Experimental use)
- No-fly zones/restricted airspace considered in routing calculations
- Multiple route options (associated with varied risk levels) displayed or toggled
- Multiple missions displayed at once or toggled
- Automated weather data/flight plan ingest
- Machine-to-Machine capabilities
- Live enroute updates as often as weather data cube updates
- Visualizations: Satellite Tool Kit (STK), FalconView, Google Earth, others?
- **USER INPUT FOR OTHER IDEAS???**

QUESTIONS???
COMMENTS???