Risk Levels for Rule-Based Weather Decision Aids

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Abstract

Rules-based weather effects decision aids, such as the Tri-Service Integrated Weather Effects Decision Aid (T-IWEDA), is a "stop-light" type of decision aid. The rules that T-IWEDA uses for differentiating the stop-light boundaries do not sufficiently represent real-world conditions. Within each T-IWEDA band (red/yellow/green) significant variation may occur. According to Army FM-34-81-1, Battlefield Weather Effects, moderate impacts (yellow regions) cover from 25 to 75% reduced normal effectiveness. Within such a large region it is unrealistic to believe that there is not a further gradation of impacts, i.e. a slow transition from red to green, rather than three abrupt, unvarying regions. To mitigate this problem a series of weather specific curves, that transition from red to yellow to green in a continuous manner, have been developed using measured and modeled resources. Parametric curves have been developed for IR sensors, helicopters, and personnel working under varied weather conditions. For a given or forecast weather condition, these curves can be used to represent the level of risk for select systems, sub-systems or components. The technique and curves are applicable for T-IWEDA and may also be used as a "penalty" within combat models.

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1. Introduction

Weather Impact Decision Aids (WIDAs) provide the battlefield commander with relevant information concerning the effectiveness of weapon systems, subsystems, components and personnel under varying weather conditions. WIDAs are either rule-based or physics-based. Rule-based routines provide qualitative information whereas physics-based routines provide quantitative information. An example of a physics-based routine is the Tri-Service Target Acquisition Weather Software (TAWS) (1). TAWS computes the detection range to a user-selected target given a user-selected sensor under various weather conditions. In contradistinction to physics-based routines, rule-based routines, such as the Tri-Service Integrated Weather Effects Decision Aid (T-IWEDA) (1), provide information on which weapon systems will work best under the forecast weather conditions; no information is provided as to the acquisition range for a target.

At the heart of T-IWEDA are the environmental impact thresholds, or rules, which identify significant weather "critical values" that characterize qualitative weather impacts on platforms, weapon systems, and operations, including Soldier performance. These rules transform raw weather data into qualifiable weather impacts. The rules are codified as red/yellow/green (unfavorable/marginal/favorable) for one or a combination of several environmental parameters that affect the system. An example of a system "red" rule might be "surface winds greater than 30 knots preclude helicopter takeoff or landing". An example of a "yellow" rule for helicopters might be "surface windspeed greater than 27 knots may impact aircraft hover." However, real life scenarios usually have a continuum of result states rather than three result states; this is particularly apparent in the case of system components such as sensors where the rules are not so definitive. For example, a "red" rule for sensors might be "if visibility is less than 1 km, target detection is not possible" and a "yellow" rule might be "if visibility is greater than 1 km, but less than 5 km, target acquisition is impaired." Obviously, sensor rules provide only general guidance; how well the sensor works in the yellow region, or how steep is the boundary fall off between green and yellow is unknown. All of T-IWEDA's rules are step functions. Examples of other rule types are: "What is the efficiency of Soldiers working in the field under extreme temperatures?" or "How does snow runoff affect river level and its subsequent impact on bridges footings?" etc. It would be useful to quantify as many of these rules as possible in and between the red-yellow-green areas. Feasibility studies have shown that many of these disparate areas can be quantified by the use of parametric curves, which can be constructed by using other, physics-based tactical decision aids (TDAs) or from measurements. Parametric curves have the additional feature of being easy to implement and are quick to execute. The curves are also useful for inclusion of weather "penalties" for wargames. For example if there is a 20% chance that a helicopter might be in an accident when wind conditions exceed a particular speed, then, if the commander decides that the mission is important enough to launch, they would have their helicopter assets penalized, or attrited, by 20%.

## 2.	Development of the Parametric Curves

### 2.1	Infrared Sensors

Environmental effects on sensors can be addressed in a unified approach by employing the TAWS TDA in conjunction with T-IWEDA. TAWS was designed to provide detection, recognition, identification, and lock-on range predictions for selected sensors and targets using physics-based models that combine the Night Vision and Electronic Sensors Directorate's (NVESD) ACQUIRE (2) algorithm and selected weather conditions, which for our purposes here, may be interpreted as meteorological visibility. Since T-IWEDA does not contain any targets or specific sensors, a methodology was developed to overcome those limitations. This methodology used TAWS in conjunction with a limited set of weather conditions that are typically encountered, while looking towards results that are amenable to interpolation.

#### 2.1.1	Methodology

Since the number of possible unlimited conditions (weather, sensor, target, time-of-day (TOD), location, geometry, etc.) is essentially infinite, a small subset of these conditions was chosen for input to TAWS. However, the methodology presented is amenable to producing curves for any combination of the above conditions.

TAWS version 2.2 was used to determine infrared (IR) sensor detection ranges for various targets, backgrounds, and weather conditions. That version of TAWS contained 26 different IR sensors, many had a choice of either narrow field-of-view (NFOV) or wide field-of-view (WFOV); 7 army-type vehicular targets with 3 operational modes (inactive, idling, exercised); 23 stationary targets; 7 surface weather types (fog, rain, etc.); 6 cloud types; and other sundry quantities. As mentioned above, since there are an unlimited number of conditions (weather, sensor, target, TOD, location, geometry, etc.) that could occur on the battlefield, the weather impact on sensors were initially examined by aggregating many of these conditions. These early experiments showed that aggregating the full range of possibilities would have been difficult to achieve and would have provided dubious results. Thus, the parameter space was restricted to cover all 26 NFOV/WFOV IR sensors; 2 targets with 4 line-of-sight (LOS) azimuths and 2 operational states; 2 seasons at 2 locations; 2 TOD; 4 visibilities; 2 aerosol types; 1 cloud type; and 2 cloud cover states. These parameters are presented in table 1.

The TAWS model was executed to cover the $26 \times 212 = 106{,}496$ possible combinations listed in table 1 and the results concatenated into a database. The actual number of TAWS runs required to cover this parameter space was considerably smaller than the number cited above, because each TAWS run outputs the results for all 26 sensors, all FOVs, and all TOD states. To reduce these data, a series of codes were constructed to extract results from the TAWS output database and, optionally, average over subsets of the various weather and target parameters chosen for this study. Although the codes can also examine a specific sensor's response to varying meteorological conditions, the detection ranges examined were aggregated by averaging over all IR sensors and various weather and equipment conditions thereby making the results more amenable for use in T-IWEDA. Due to the large number of possible combinations that could be considered (even in this limited database), an average over 116

arbitrarily chosen combinations was performed and detection range determined primarily as a function of visibility, aerosol type, and sensor FOV.

Table 1. Parameter space used for determination of parametric curves.

26 IR Sensors		
▪ FOV	▪	narrow and wide
▪ platform	▪	helicopter at 300' altitude
▪ LOS azimuth	▪	N, S, E, W
Targets		
▪ platform	▪	T80 and armored personnel carrier (APC)
▪ state	▪	inactive and exercised
▪ orientation	▪	north facing
Meteorology		
▪ visibility	▪	0.1, 1.0, 10, 100 km
▪ aerosols (3)	▪	rural (50% relative humidity),
▪ cloud cover		fog (moderate radiation)
	▪	cloudless, overcast
Locale		
▪ longitude	▪	0°
▪ latitude	▪	0°, 30° N
▪ background	▪	desert sand
Season		
▪ 0° (equator)	▪	equinox and winter solstice
▪ 30° N	▪	summer and winter solstices
TOD		0900 and 1500

Once these averages were available, the detection ranges for the various combinations were normalized, and subsequently fit to a third order polynomial (4) as explained below. To assure a better fit for calculation of these third order polynomials, 3 "synthetic" data points were added between the 4 detection ranges at visibilities of 0.1, 1.0, 10.0, and 100.0. The 4 input data points are assumed to be evenly spaced in ln space, so that the 3 synthetic points are midway in both ln x and ln y. The polynomial takes the following form:

$$Ndr = a_0 + a_1 \times \ln(Vis) + a_2 \times \ln(Vis)^2 + a_3 \times \ln(Vis)^3, \tag{1}$$

where Ndr is the normalized detection range, Vis is the visibility in km, and a_0-a_3 are the third order polynomial coefficients.

2.1.2 Application to T-IWEDA

The application of these parametric sensor acquisition curves to T-IWEDA's red/yellow/green impact cells is straight forward. Using averages over azimuth and TOD as an example, figure 1 presents the individual curves (colored) for an inactive tank viewed with a NFOV sensor under ground fog and clear winter sky conditions in the morning (0900) and afternoon (1500): all sensors and locations were averaged over. This figure details the effects of vehicle orientation on target acquisition and can be examined to ascertain whether there is a significant difference in detection range over these orientations or TOD values. An explanation of the monikers in the legend of figure 1 is shown in table 2. Each

Table 2. Monikers and their meaning.

Moniker	Meaning	Moniker	Meaning	Moniker	Meaning
Fog	Fog	900	0900	Sou	South
Rur	Rural	150	1500	Eas	East
Tan	Tank	Win	Winter	Wes	West
Exe	Exercised	Sum	Summer	Ove	Overcast
Off	Inactive	Nor	North	Cle	Clear

moniker is a concatenation of the various atmospheric conditions that were used; with the exception of the 0900 time period, the first three characters of each atmospheric condition were used.

Since these individual curves detailing azimuth and TOD effects are closely bunched and do not vary strongly as a function of the parameters examined (azimuth and TOD), they are candidates for a composite curve. Such composite curves, independent of azimuth (a), and azimuth and TOD (b), were computed and are shown in figure 1. Note that these composite curves were determined, not by averaging the individual curves or their coefficients, but rather by recomputing new coefficients for the
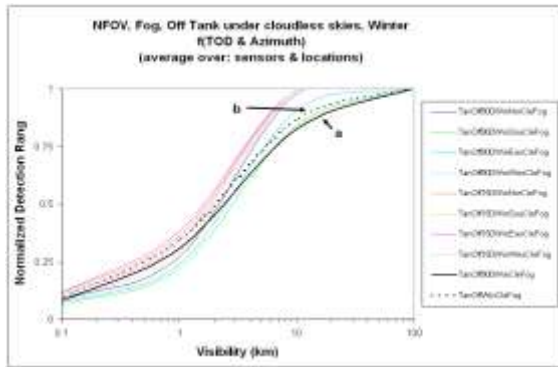

Figure 1. Normalized Detection Range as a function of target state and orientation, averaged over NFOV IR sensors, and locations (see table 1).

Note: The scenario parameters are a tank in the inactive state, under cloudless skies, with ground fog in the morning at 0900 and afternoon at 1500. Also shown are composite curves independent of azimuth (a) and azimuth and TOD (b).
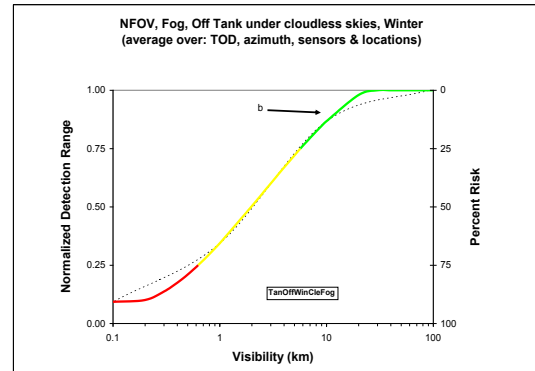

Figure 2. Composite curve (b in figure 1) averaged over NFOV IR sensors, locations, azimuths, and TOD (see table 1).

Note: The scenario parameters are a tank in the inactive state, under cloudless skies, with ground

weather conditions, sensors, etc., that were averaged over. Figure 2 shows the four point composite curve "b" (from figure 1) in more detail. In addition, figure 2 also shows the associated composite parametric curve with the T-IWEDA red/yellow/green regions, at the "standard" boundaries of 75% and 25% (since the parametric curves are third order polynomials, it was graphed with more points than the four point dotted curve and, therefore, apparently deviates from the dotted curve). As a consequence of parameterization and normalization, not only is there a continuum of values, but the percent risk associated with these curves can immediately be determined. In figure 2, a secondary axis has been

added on the right hand side for the percent risk which, for the sensor curves, is nothing more than one minus the normalized detection range. This can be done for any of the combinations for which TAWS runs have been made or, if the particular combination desired is not available, TAWS can be run for those conditions. The coefficients for the parameterized curves for 116 possible combinations may be found in (5). The particular curve in figure 2 can be represented by the third order polynomial

$$Ndr = 0.3441 + 0.2159 \ \ln(Vis) + 0.0257 \ \ln(Vis)^2 - 0.0090 \ \ln(Vis)^3 \qquad (2)$$

or, in terms of percent risk

$$R = (1.0 - Ndr) \times 100 = 66.59 - 21.59 \ \ln(Vis) - 2.57 \ \ln(Vis)^2 + 0.90 \ln(Vis)^3, \qquad (3)$$

where R is the percent risk.

2.2 Personnel

Where data exists parameterization can be carried out for other, non-sensor, areas. The effect of temperature on Army personnel manual and equipment tasks may be examined using data found in (6). Figure 3 graphically presents that information where it is noted that there is a range of values suitable for parameterization. For the equipment tasks (dashed lines) the upper and lower curves for equipment and manual tasks can be represented, respectively, as
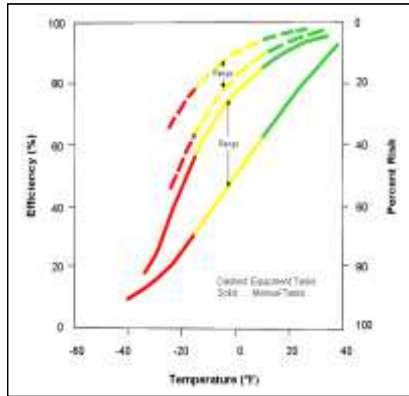
$$Eff_{up\text{-}equip} \ \ = 90.101 + 0.5144 \ T - 0.0151 \ T^2 + 0.0003 \ T^3, \quad (4)$$

$$Eff_{lwr\text{-}equip} \ = 81.971 + 0.9167 \ T - 0.0202 \ T^2 + 0.0002 \ T^3, \quad (5)$$

$$Eff_{up\text{-}manual} = 76.345 + 1.0777 \ T - 0.0192 \ T^2 + 0.0001 \ T^3, \quad (6)$$

$$Eff_{lwr\text{-}manual} = 49.315 + 1.3158 \ T + 0.0014 \ T^2 - 0.0002 \ T^3, \quad (7)$$

where Eff is the percent efficiency (subscripts up/lwr (upper/lower) refer to the respective equipment or manual curves), and T is the temperature in °F.

2.2.1 Application to T-IWEDA

Figure 3. Effect of temperature on manual and equipment tasks on personnel (7).

Since T-IWEDA is a qualitative TDA, it is desirable to express equations 4 through 7 as a percent risk, and to also have only one curve for each of the two types of tasks. This is easily accomplished and the equations representing the equipment and manual tasks are

$$R_E \ \ = \tfrac{1}{2} \ (Eff_{up\text{-}equip} + Eff_{lwr\text{-}equip})$$

$$= 86.036 + 0.7156 \ T - 0.0177 \ T^2 + 0.00025 \ T^3 \qquad (8)$$

and

$$R_M \ = \tfrac{1}{2} \ (Eff_{up\text{-}manual} + Eff_{lwr\text{-}manual})$$

$$= 62.83 + 1.1968 \ T - 0.0089 \ T^2 - 0.00005 \ T^3 \qquad (9)$$

where R_E is the percent risk for equipment tasks and R_M is the percent risk for manual tasks (see right-hand scale, figure 3). These equations must be broken into T-IWEDA regions of applicability. In this case the red/yellow boundary is about -15 °F and the yellow/green boundary is about 20 °F.

2.3   Aircraft

The National Aviation Safety Data Analysis Center (NASDAC) analysis staff performed a study of the National Transportation Safety Board (NTSB) accident and incident database to identify aviation accidents where weather was a causal or contributing factor to an accident. Figures 4 and 5 present a graphical representation of that data for Federal Aviation Administration (FAA) Parts 91 (8) and 135 (9), respectively. Federal Aviation Regulations, or FARs, are rules prescribed by the FAA governing all aviation activities in the United States.
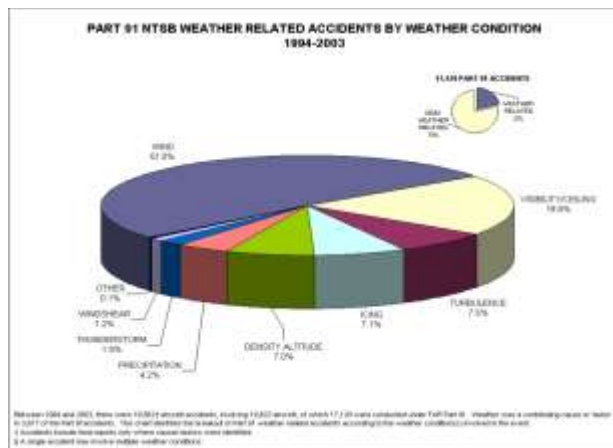

Figure 4. FAA Part 91 NTSB weather related accidents by weather condition (8).
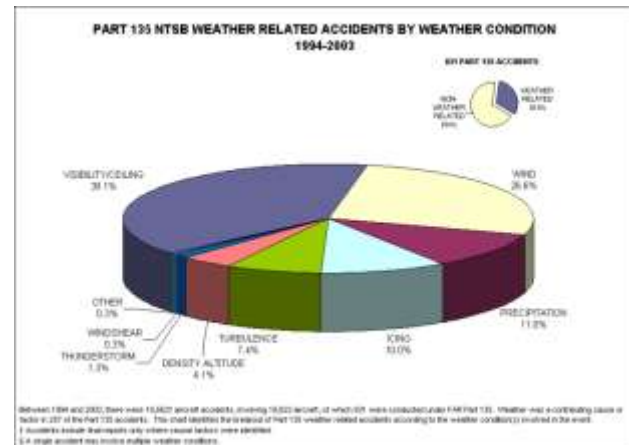

Figure 5. FAA Part 135 NTSB weather related accidents by weather condition (9).

2.3.1   Helicopters

FAA Part 91 and on-demand Part 135 include helicopters. For helicopters we consider Navy data from Cantu (10), and NTSB data for Part 91 and on-demand Part 135. Data from figures 4 and 5, from NTSB's 2003 accident reports for Parts 91 and 135, and from Cantu's study on Navy weather related aviation accidents is presented in table 3 (8 – 12). We note than since only 2% of Part 135 is scheduled, we assume that figure 5 values apply directly to on-demand Part 135.

Table 3. Data used in determination of helicopter accidents that involve weather.

Quantity \ Source	Part 91	On-demand Part 135	Navy
No. aircraft accidents	1758	74	395
No. helicopter* accidents	197	27	104
% helicopter accidents	11	36.5	26
No. environmental accidents**	754	-	-
No. environmental accidents due to weather**	357	-	-
Percent environment accidents due to weather	47	-	-
Percent helicopter accidents w/in environment	36	-	-
Percent weather related accidents for fleet (all aircraft)	21	30.9	12
% of all weather related helicopter accidents	16.9	27.3	**18**
% of weather related helicopter accidents	1.9	9.9	**5**

* rotorcraft (helicopters; gyroplanes and gyrodynes – rotor provides lift only).
** environment is comprised of: weather, terrain, object, light condition, airport.

The last two rows in table 3 are the quantities that are desired: percent of all weather related helicopter accidents, i.e., the number weather related helicopter accidents/total number of helicopter accidents, and percent of weather related helicopter accidents, i.e., the number of helicopters in weather related accidents/total number of aircraft accidents. The former would be of use to wargames and commanders who have access to current weather and want to know the risk of launching a helicopter under those current weather conditions. The latter would be of use to mission planners using long-range forecasts. However, which of these table 3 values to use, Part 91, on-demand Part 135, or Navy, is problematic.

Since the Navy data was taken from a military environment and that data falls between the Part 91 and Part 135 data, we shall use the Navy data, presented in bold in table 3, in the development of risk values for T-IWEDA. Thus, for mission planning purposes, we define the percent of weather related helicopter accidents, as $A_{w\text{-}mp}$. From table 3 this value, 5%, is thus the percent of helicopters involved in weather accidents compared to all aircraft accidents. For command purposes, we define $A_{w\text{-}cmd}$ as the percent of all weather related helicopter accidents, that is, the number of helicopters involved in weather-related accidents compared to the total number of helicopter accidents. Again from table 3, this value is 18%.

Since helicopters are more often subject to weather accidents than fixed-wing aircraft (10), these values are most likely conservative numbers. Finally, it should be noted that Cantu presents compelling information that, if human factors are included, weather related accident rates are considerably higher.

We are now in a position to provide more detail regarding helicopter accidents due to weather conditions. The values in table 3 apply to "average" weather: we can use additional information from either NTSB's or the Navy's distributions of weather related accidents by weather condition (see figure 6). While Cantu's values fall between the NTSB Part's values, there is compelling reason to use the NTSB's data for detailing the percent of helicopter accidents from weather conditions. First, the NTSB data applies primarily over ground, where terrain is bound to influence weather conditions. Further, the NTSB weather related accidents by weather condition (figure 6 (13)) for all parts has been broken down even further with respect to wind (figure 7 (14)) and visibility (figure 8 (15)).

Using table 3 information ($A_{w\text{-cmd}} = 18\%$; $A_{w\text{-mp}} = 5\%$) coupled with additional information from figures 6, 7, and 8, we have constructed table 4, detailing the occurrence of helicopter accidents due to various weather conditions and/or components for command and mission planning purposes. In using the data from figures 7 and 8, the tacit assumption has been made that statistics from these components are aircraft type independent.
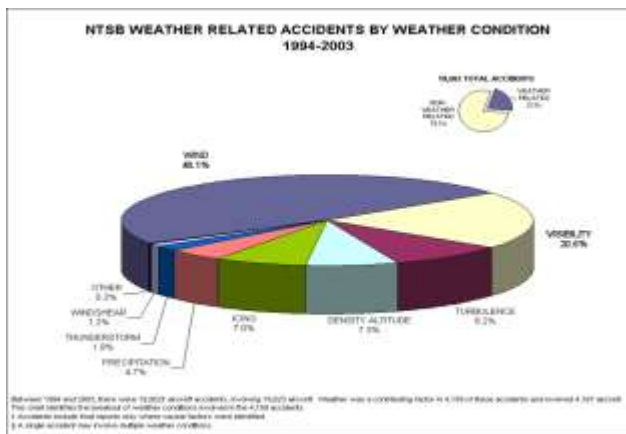

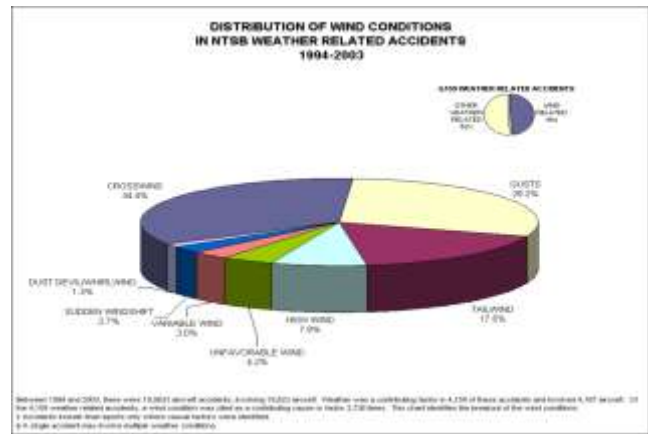Figure 6. NTSB weather related accidents by weather condition (14)

Figure 7. FAA Part 135 NTSB weather related accidents by weather condition (12).
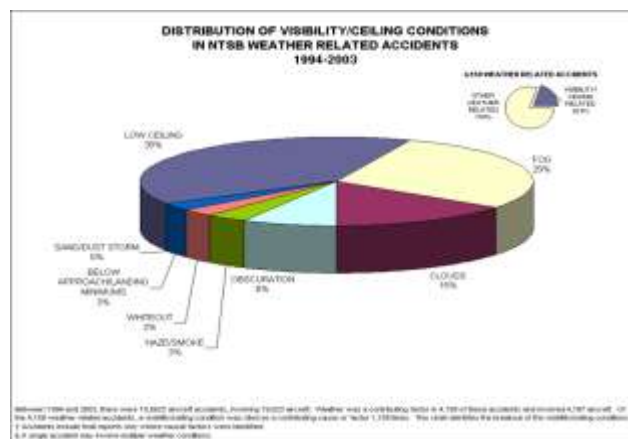

Figure 8. Distribution of visibility/ceiling conditions in NTSB weather related accidents (16).

Table 4. Percent helicopter accidents by weather condition for command ($A_{w\text{-}cmd}$) and mission planning ($A_{w\text{-}mp}$) purposes, including detailed effects of visibility/ceiling and wind conditions.

Weather Condition	$A_{w\text{-}cmd}$ (%)		$A_{w\text{-}mp}$ (%)	
Visibility/Ceiling	3.7		1.0	
	Low ceiling	1.4	Low ceiling	0.4
	Fog	1.1	Fog	0.3
	Clouds	0.6	Clouds	< 0.2
	Obscuration	0.3	Obscuration	< 0.1
	Haze/smoke	0.1	Haze/smoke	< 0.1
	Whiteout	0.1	Whiteout	< 0.1
	Below approach/ landing minimums	0.1	Below approach/ landing minimums	< 0.1
	Sand/dust storm	< 0.1	Sand/dust storm	< 0.1
Wind	8.6		2.4	
	Crosswind	3.0	Crosswind	0.8
	Gusts	2.5	Gusts	0.7
	Tailwind	1.5	Tailwind	0.4
	High wind	0.7	High wind	0.2
	Unfavorable wind	0.4	Unfavorable wind	0.1
	Variable wind	0.3	Variable wind	< 0.1
	Sudden windshift	0.2	Sudden windshift	< 0.1
	Dust devil/ whirlwind	0.1	Dust devil/ Whirlwind	< 0.1
Turbulence	1.7		0.5	
Density altitude	1.3		0.4	
Icing	1.3		0.4	
Precipitation	0.8		0.2	
Thunderstorm	0.3		0.1	
Windshear	0.2		< 0.1	
Other	0.0		0.0	

2.3.2 Application to T-IWEDA

To make use of the information in table 4, we must consider the red/yellow/green boundaries in T-IWEDA. For rotary-wing aircraft, general operations, a surface wind speed value for the red/yellow boundary is 30 kts and for the yellow/green boundary is 20 kts (16). We now have two points which can be used in the construction of piecewise linear curves: at zero wind speed there will be zero accidents due to wind, and at some wind speed above 30 kts (the red/yellow boundary value), there will be 100% accidents due to wind. The third point will be taken from table 4 – either an 8.6% or 2.4% accident rate due to winds. However, since the accident rates in table 4 represent weather-related accidents for all helicopters under varied wind conditions, the abscissa point (8.6% or 2.4%) for the accident rate probably should not be anchored at the red/yellow boundary. Instead, we will anchor it at halfway between the red/yellow and yellow/green boundaries, or in this instance, at 25 kts. This practice will be
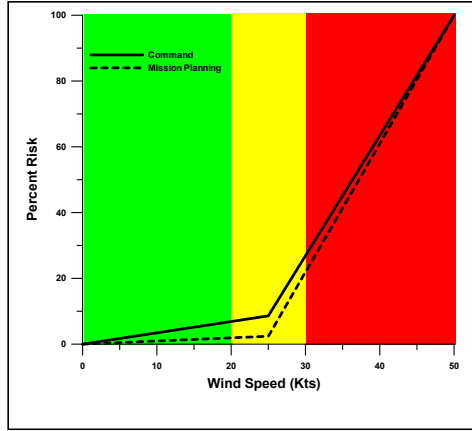
Figure 9. Piecewise linear curves for weather-related helicopter risk for command and mission planning purposes.

followed for all accident rates. Finally, an upper wind speed value must be chosen, a point where one would expect there to be a 100% chance of an accident occurring. This upper value has been chosen here as 50 kts. Therefore for command, the piecewise linear equations will be

$$A_{\text{w-cmd}} = R_{\text{w-cmd}}\Big|_0^{25} = 0.344 \times Ws, \qquad (10)$$

and

$$A_{\text{w-cmd}} = R_{\text{w-cmd}}\Big|_{25}^{50} = 3.656 \times Ws - 82.8, \qquad (11)$$

where Ws is the wind speed in knots and $R_{\text{w-cmd}}\Big|_0^{25}$ and

$R_{\text{w-cmd}}\Big|_{25}^{50}$ are the percent risk for wind-related helicopter accidents for command purposes – the abscissa limits on $R_{\text{w-cmd}}$ are the beginning point (0), the accident rate point (25), and the upper value point (50). The analogous equations for mission planning purposes are

$$A_{\text{w-mp}} = R_{\text{w-mp}}\Big|_0^{25} = 0.096 \times Ws, \qquad (12)$$

and

$$A_{\text{w-mp}} = R_{\text{w-mp}}\Big|_{25}^{50} = 3.904 \times Ws - 95.2, \qquad (13)$$

where $R_{\text{w-mp}}\Big|_0^{25}$ and $R_{\text{w-mp}}\Big|_{25}^{50}$ are the percent risk for wind-related helicopter accidents for mission planning purposes and Ws is as defined above. Equations 10 through 13 are presented graphically in figure 9.

The general category visibility/ceiling can be broken down using the NTSB and Cantu data. Thus we will assume that ceiling alone contributes 1.4/0.4% of helicopter accidents, and low visibility conditions contribute the rest, or 2.3/0.6% for command/mission respectively. Using the methodology above, table 5 presents equations for those weather conditions where suitable T-IWEDA boundary values (17, 18) exist. To anchor the 0% and 100% accident rates, a suitable value for the minimum and maximum boundary values were chosen. Where maximum ceiling heights were unknown, an upper limit of 100 hft was chosen.

Table 5. Helicopter weather related accident rate using piecewise linear curves where "general operations" boundary
values for red/yellow (r/y) and yellow/green (y/g) exist.

Weather Condition (units)	Boundary Values -minimum and r/y- -y/g and maximum-	$R_{w\text{-}cmd}$ (%)	$R_{w\text{-}mp}$ (%)
Visibility (Vis) km	0.0 – 0.8 1.6 – 11.0	$-81.417 \times Vis + 100$ $0.235 \times Vis + 2.582$	$-82.833 \times Vis + 100$ $-0.056 \times Vis + 0.667$
Ceiling (Ce)** ft	0 – 100	$-0.986 \times Ce + 100$	$-0.996 \times Ce + 100$
Wind (Ws) kts	0 – 30 20 – 50	$0.344 \times Ws$ $3.656 \times Ws - 82.8$	$0.096 \times Ws$ $3.904 \times Ws - 95.2$
Density altitude (Da) hft	0.0 – 40.0 69.0 – 100.0	$0.024 \times Da$ $2.169 \times Da - 116.911$	$7.339 \times 10^{-3} \times Da$ $2.189 \times Da - 118.901$
Icing (lwc) g/m³	0 – 0.375* 0.75* – 5.0	$2.311 \times lwc$ $22.242 \times lwc - 11.211$	$0.711 \times lwc$ $22.445 \times lwc - 12.225$
Precipitation (rr) mm/h	0.0 – 0.625* 2.5* – 5.0	$0.512 \times rr$ $3.438 \times rr - 4.571$	$0.128 \times rr$ $29.033 \times rr - 45.164$

NOTE: Minimum and maximum boundary values are also specified.
* Average value for Moderate/light intensity
** Boundary is directly from red to green

2.4   Ground Vehicles

2.4.1   Ice Thickness

For vehicles traversing frozen rivers or lakes the thickness of the ice is an important factor. Currently T-IWEDA has only one boundary for this type of rule (i.e., red directly to green), dependent upon vehicle type. FM 90-13/MCWP 3-17.1 (19) presents graphs and equations applicable to wheeled and tracked vehicles:

$$Class_W = (T^2 \times C \times S)/25 \qquad\qquad (14)$$

and

$$Class_T = (T^2 \times C \times S)/20 \qquad\qquad (15)$$

where $Class_W$ and $Class_T$ are the Military Load Classification (MLC) for wheeled or tracked vehicles, respectively, T is the ice thickness in inches, C is the ice color factor, and S is the ice strength factor. The MLC is a standard system in which a route, bridge, or raft is assigned class number(s) representing the load it can carry. Vehicles are also assigned number(s) indicating the class of route, bridge, or raft they are authorized to use. In figure 10, which shows graphs of equations 14 and 15, an average T-IWEDA threshold (red→green) has been added.
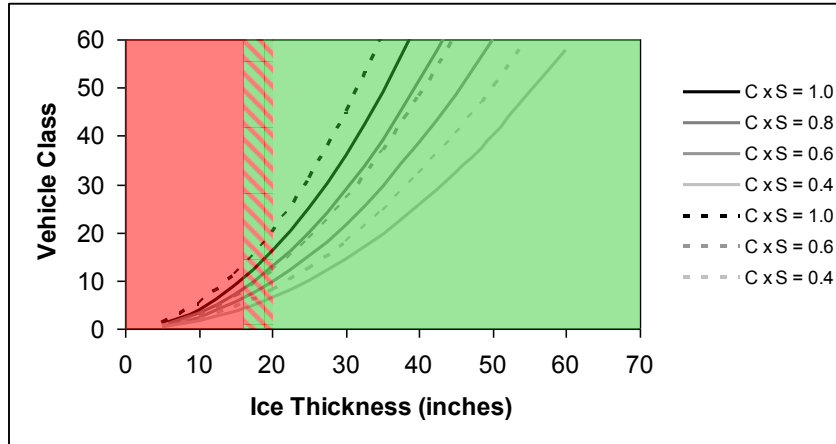
Figure 10. Ice thickness vs. vehicle class with representative T-IWEDA boundaries.
The solid lines are wheeled; the dotted lines are tracked.

Here there is only one boundary going from red directly to green. The crosshatched area represents the different boundaries for wheeled (red up to ~15 in.) and tracked (red up to ~20 in.) vehicles. In order to use this graph, the MLC system, which is vehicle specific, needs to be coupled with T-IWEDA's vehicle types. Unfortunately T-IWEDA does not link vehicle type with MLC. Until that occurs, U.S. Army Engineer School values (20) need to be manually cross referenced with individual vehicle rules.

2.4.2 Application to T-IWEDA

Assuming that the MLC values have been added to the CRDB, the application of equations (14) and (15) to T-IWEDA are straightforward. These equations would have two regions of applicability, 0 – 15 and 15 – 60 for wheeled vehicles and 0 – 20 and 20 – 60 for tracked vehicles.

3. Conclusions

With some judicious choices, many of the T-IWEDA rules can have analytic functions fitted across the step-function boundaries. Since T-IWEDA does not contain quantitative information, other TDAs and sources were used to determine the analytic functions. In particular, information on IR sensors was derived from running TAWS under selected weather conditions. This information was then averaged, curve fit to a third order polynomial as a function of visibility, and concatenated into a data base. Curves, for personnel working in cold regions, were fit and expressed as a function of either manual work or working with equipment. Weather effects on helicopters were also examined. Here NTSB and Navy data were used to determine statistics on weather-related accidents for helicopters. Using that information coupled with boundary limits from the T-IWEDA rule set, piecewise linear curves were fit for a number of weather conditions that contribute to these type of accidents. Finally, the military load factor for vehicles crossing bridges was examined. It was determined that the T-IWEDA rules currently do not contain enough information for this feature to be implemented.

References

1. Shirkey, R.C.; Gouveia, M. Weather Impact Decision Aids: Software to Help Plan for Optimal Sensor and System Performance, Crosstalk, the Journal of Defense Software Engineering **2002**, 15, (12), 17–21.

2. ACQUIRE 1995. ACQUIRE Range Performance Model for Target Acquisition Systems 1995, Version 1 User's Guide, U.S. Army CECOM Night Vision and Electronic Sensors Directorate Report.

3. Shirkey, R.C.; Tofsted, D. High Resolution Electro-Optical Aerosol Phase Function Database PFNDAT 2006, ARL-TR-3877, U.S. Army Research Laboratory: White Sands Missile Range, NM, 2006 (ADA458924).

4. Press, W. H.; Teukolsky, S. A.; Vetterling, W. T.; Flannery, B. P. Numerical Recipes in Fortran 77: The Art of Scientific Computing, 2nd ed ., Cambridge University Press: New York, NY, 2003.

5. Shirkey, R.C., Determination of Risk Levels for Rule-Based Weather Decision Aids, Army Research Laboratory Technical Report ARL-TR-4586, September 20008.

6. Richmond, P., Ed. Notes for Cold Weather Military Operations, Cold Regions Research and Engineering Laboratory Special Report 91–30, December 1991.

7. Abele, G., Effect of Cold Weather on Productivity, in Technology Transfer Opportunities for the Construction Engineering Commmunity, Cold Regions Research and Engineering Laboratory Miscellaneous Publication MP2152, 1986. http://www.crrel.usace.army.mil/library/frequentlyrequested.html

8. http://www.asias.faa.gov/aviation_studies/weather_study/part91.html

9. http://www.asias.faa.gov/aviation_studies/weather_study/part135.html

10. Cantu, Ruben A. The Role Of Weather In Class A Naval Aviation Mishaps FY90–98, Master's Thesis, Naval Postgraduate School, Monterey, CA, March 2001.

11. Annual Review of Aircraft Accident Data, U.S. General Aviation, Calendar Year 2003, National Transportation Safety Board/ARG-07/01, PB2007-105388, November 29, 2006.

12. Annual Review of Aircraft Accident Data, U. S. Air Carrier Operations Calendar Year 2003, National Transportation Safety Board/ARC-07/01, PB2007-105389, December 2006.

13. http://www.asias.faa.gov/aviation_studies/weather_study/categories.html

14. http://www.asias.faa.gov/aviation_studies/weather_study/windcond.html

15. http://www.asias.faa.gov/aviation_studies/weather_study/viscecon.html

16. Intelligence Preparation of the Battlefield, FM 34-130, p. B-21, Dept. of Army, Washington D.C., July 1994.

17. The Centralized Rules Data Base, https://www.us.army.mil/suite/page/494483

18. Operator's Manual for UH-60A Helicopters, Uh-60L Helicopters and EH-60A Helicopters, TM 1-1520-237-10, p. 5-23, Dept. of Army, Washington D.C., April 2000.

19. River-Crossing Operations, FM 90-13/MCWP 3-17.1, Dept. of Army, Washington D.C., January 1998.

20. http://www.wood.army.mil/cellx/information%20folders/mil%20load%20class/mlc%20web%20document.html

Risk Levels for Rule-Based Weather Decision Aids

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TECHNOLOGY DRIVEN. *WARFIGHTER FOCUSED.*

A rule is simply a <u>critical value</u> associated with a <u>specific system</u>

e.g. Surface winds greater than <u>30 knots</u> preclude <u>helicopter</u> takeoff or landing

Using critical values these rules are coded into severe, moderate, or no impact. The rule above would be red. An example of a yellow rule for the same system would be

Surface windspeed greater than 27 knots may impact aircraft hover

TECHNOLOGY DRIVEN. **WARFIGHTER FOCUSED.**

Army FM 34-81-1, Battlefield Weather Effects, defines severe as reducing normal effectiveness greater than 75%, moderate as reducing normal effectiveness from 25 – 75%, and no impact as a reduction in normal effectiveness less than 25%
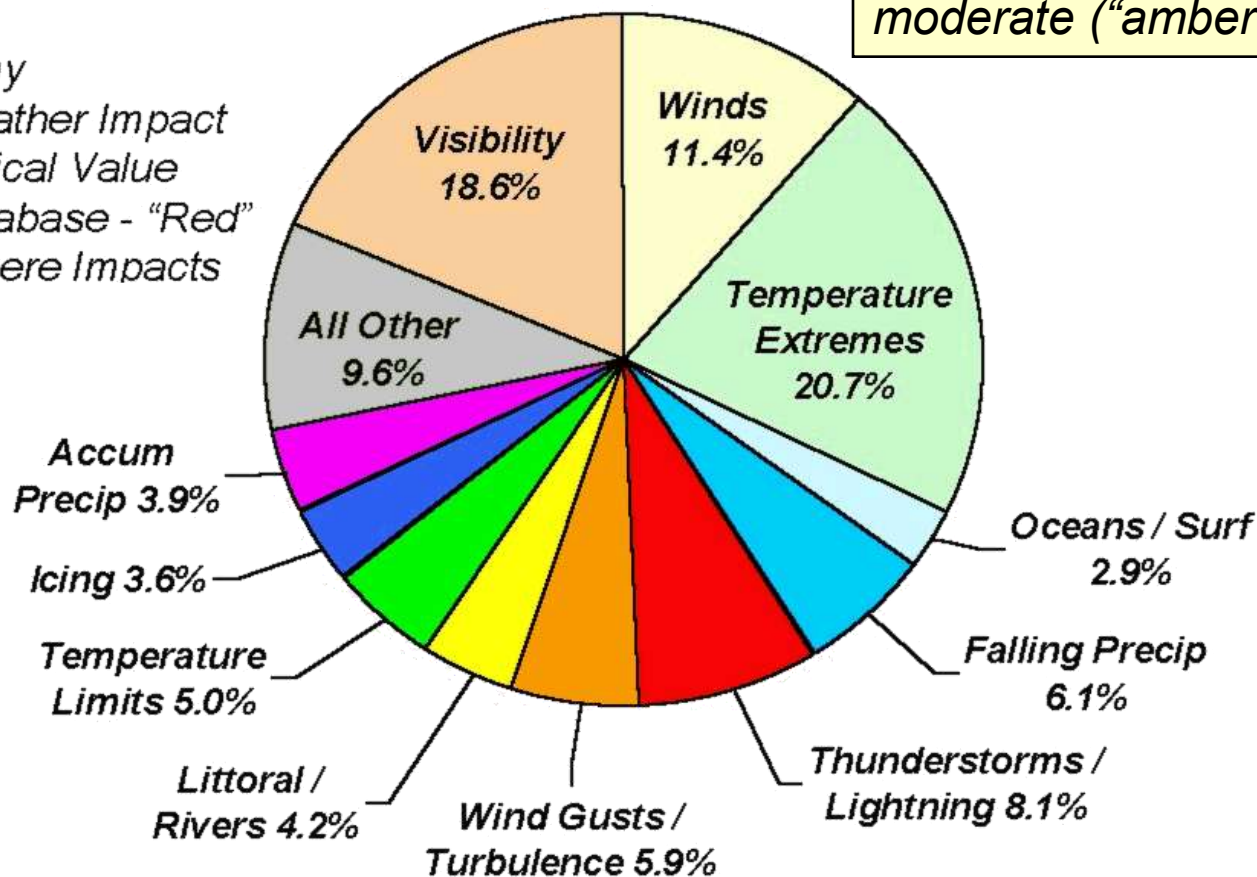
Impact	Criteria
Green (favorable)	Degradation < ~25%
Amber (marginal)	Degradation = ~25 to ~75 %
Red (unfavorable)	Degradation > ~75%

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Rules are collected from service specific field manuals, training centers and schools.

The Weather Impacts Database will contains more than 11000 weather impact rules and critical value thresholds for severe ("red") and moderate ("amber") impacts

They fall into these 12 critical value parameter categories

(Visibility includes low clouds, fog and reduced visual/IR sensor ranges)

Army Weather Impact Critical Value Database - "Red" Severe Impacts

Pie chart:
- Winds 11.4%
- Temperature Extremes 20.7%
- Oceans / Surf 2.9%
- Falling Precip 6.1%
- Thunderstorms / Lightning 8.1%
- Wind Gusts / Turbulence 5.9%
- Littoral / Rivers 4.2%
- Temperature Limits 5.0%
- Icing 3.6%
- Accum Precip 3.9%
- All Other 9.6%
- Visibility 18.6%

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Coupled with forecast weather they identify impacts on planned operations

- produces actionable intelligence
- can be used for "deltas"
- rapid environmental assessment

T-IWEDA

*TECHNOLOGY DRIVEN. **WARFIGHTER FOCUSED.***

T-IWEDA stands for the Tri-Service Integrated Weather Effects Decision Aid

It is a collection of system rules with associated critical values for aiding the commander select an appropriate platform, system or sensor under given weather conditions

Results are displayed via a red/amber/green color matrix overlaid on a background map

The Tri-Service Integrated Weather Effects Decision Aid (T-IWEDA) is fielded to the US Army, Navy and Air Force

Forecast Weather

- **Provides weather impacts on military assets (missions, operations, systems, equipment, resources/infrastructure)**

Critical Values

- **Compares critical environmental thresholds (rules) against forecast values for environmental data parameters.**

Threshold criteria for IWEDA rules:

Impact	Criteria
Green (favorable)	**Degradation < ~25%**
Amber (marginal)	**Degradation = ~25 to ~75 %**
Red (unfavorable)	**Degradation > ~75%**

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US ARMY
RDECOM

ARL

Tri-Service IWEDA

File   Edit   Screen   Help

List   **Selected**   **Map**   **Asset Info**

46000
39100
32100
25100

NBC CHEM
NBC SMOK
NIGHT VIS
NIGHT VIS
NIGHT VIS
NOE FLIGH
OH-58A/C
OH-58C
OH-58D
OH-6A CA
OUTRIDEF
PARADRO
PERSONNE
PERSONNE
PERSONNE
PERSONNE
PPS-5B
PREDATOI
RC-12
RC-12D G
RC-12H/K

No special condition

Assets
- **RQ-5A HUNTER**
  - **R** **Rules for RQ-5A HUNTER**
  - **Ss** **SubAssets of RQ-5A HUNTER**
- **HMMWV**
- **PERSONNEL/LAND**

1:18,679,652

Selected Assets impacts 19Sep2006 0000Z

30

-112   -110   -108   -106   -104   -102   -100

Lat, Lon (30.159, -111.733) - x, y (64,225)

Select

18100

11200

4200

WEM   **Impacts**

Impacts at Lat, Lon (32.068, -107.460), 19Sep2006 0000Z

| Asset: **RQ-5A HUNTER** |
| Rule: Marginal Impact: Turbulence aloft makes controlling the UAV difficult. |
| Type: Marginal Impact |
| Source: (TM 9-5895-692-10,Ch.1 1997) |
| Clause: turbulenceintensity>none |
| Clause: heightmsl<15000.0 feet |
| > |

Forecasts   **Subdomains**   **Heat Stress**

○ Planning
○ Current Ops

Select All
Deselect All
Recenter
Refresh

19Sep2006 0000Z
19Sep2006 0300Z
19Sep2006 0600Z
19Sep2006 0900Z
19Sep2006 1200Z
19Sep2006 1500Z
19Sep2006 1800Z
19Sep2006 2100Z
20Sep2006 0000Z
20Sep2006 0300Z

19Sep2006 0000Z

- **T-IWEDA rules are implemented in terms of step function stop light charts**
  - **Red-Yellow-Green**
  - **Boundaries are 75% (R/Y) and 25% (Y/G) reduction in effectiveness**

- **Reality dictates boundaries should be fuzzy**

- **An extremely useful piece of information would be knowing how quickly, or at what rate, transitions occur between and within the red/yellow/green boundaries/cells**
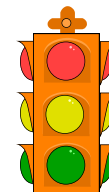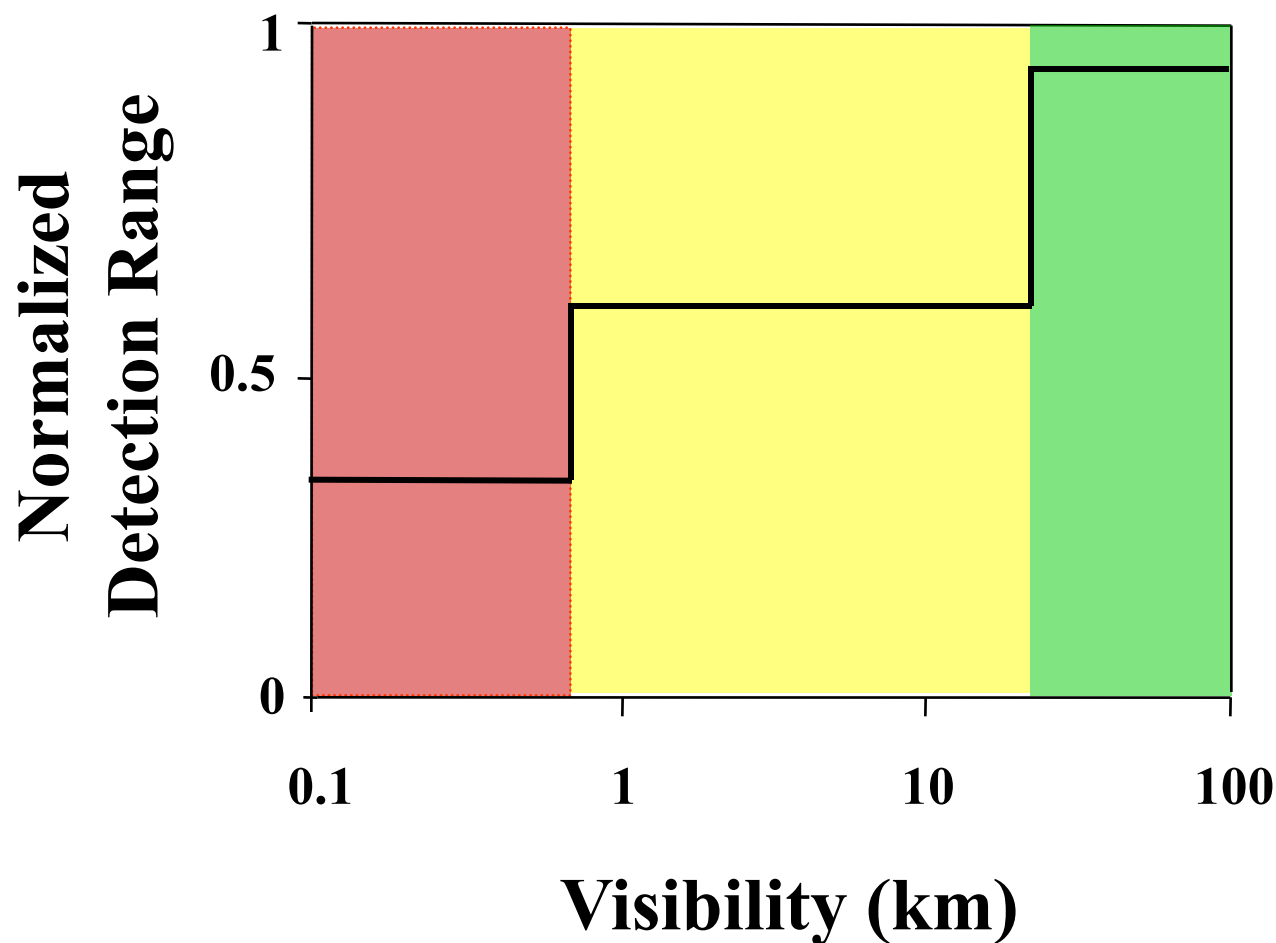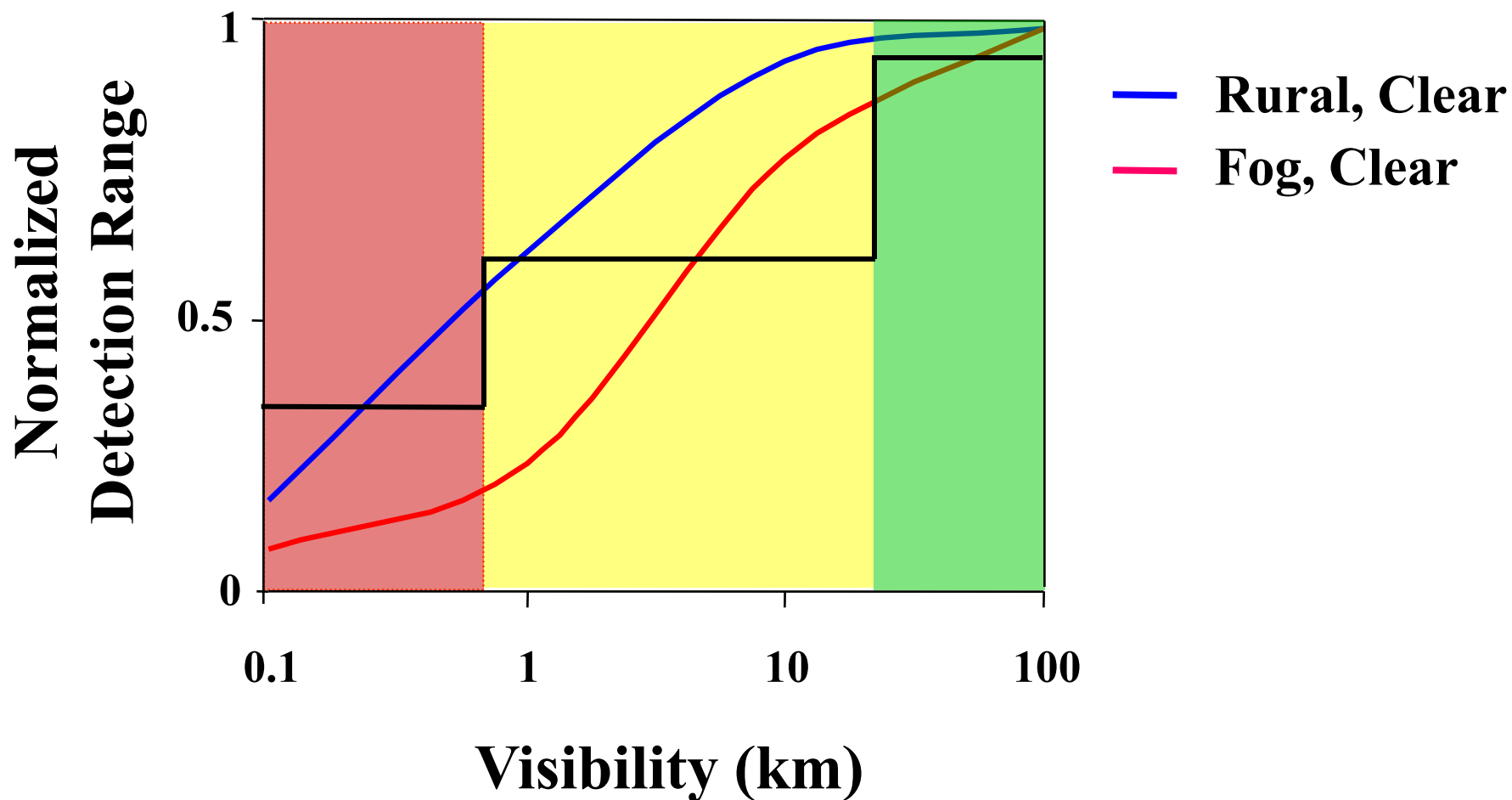
• **To mitigate the step function problem, a series of weather specific curves that transition from red to yellow to green in a continuous manner have been developed using measured and modeled resources for**

- **IR Sensors**
- **Helicopters**
- **Cold weather personnel**
  equipment and manual tasks

IR Sensors

• **The Target Acquisition Weapons Software (TAWS) was run for select weather & target geometries.**

TAWS provides acquisition ranges as a function of weather, target type and time of day

26 IR Sensors ▪ FOV ▪ platform ▪ LOS azimuth	▪ narrow and wide ▪ helicopter at 300' altitude ▪ N, S, E, W
Targets ▪ platform ▪ state ▪ Orientation	▪ T80 and armored personnel carrier (APC) ▪ inactive and exercised ▪ north facing
Meteorology ▪ visibility ▪ aerosols ▪ cloud cover	▪ **0.1, 1.0, 10, 100 km** ▪ rural (50% relative humidity), fog (moderate radiation) ▪ cloudless, overcast
Locale ▪ longitude ▪ latitude ▪ Background	▪ 0 ▪ 0 , 30 N ▪ desert sand
Season ▪ 0 (equator) ▪ 30 N	▪ equinox and winter solstice ▪ summer and winter solstices
TOD	0900 and 1500
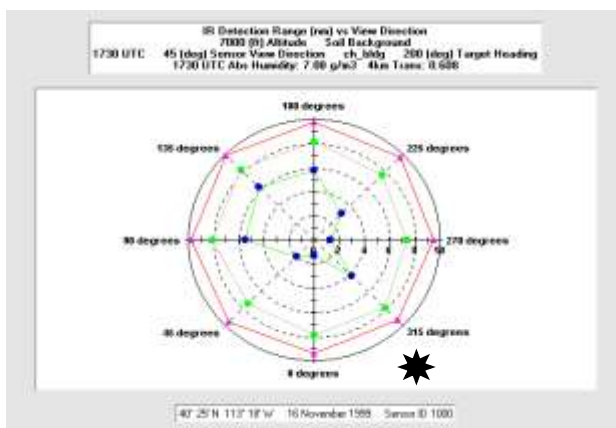
NFOV, Fog, Off Tank under cloudless skies, Winter f(TOD & Azimuth) (average over: sensors & locations)
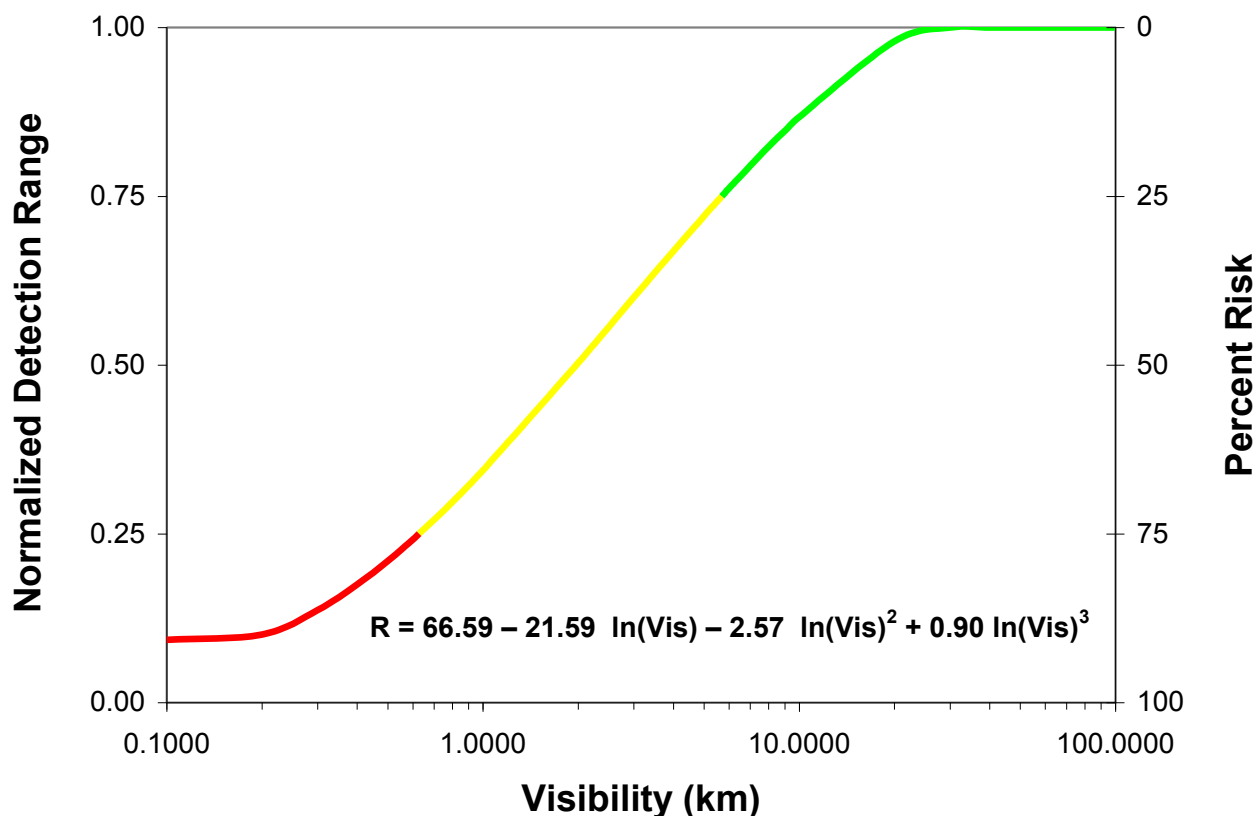
26 IR Sensors
T-62 Tank
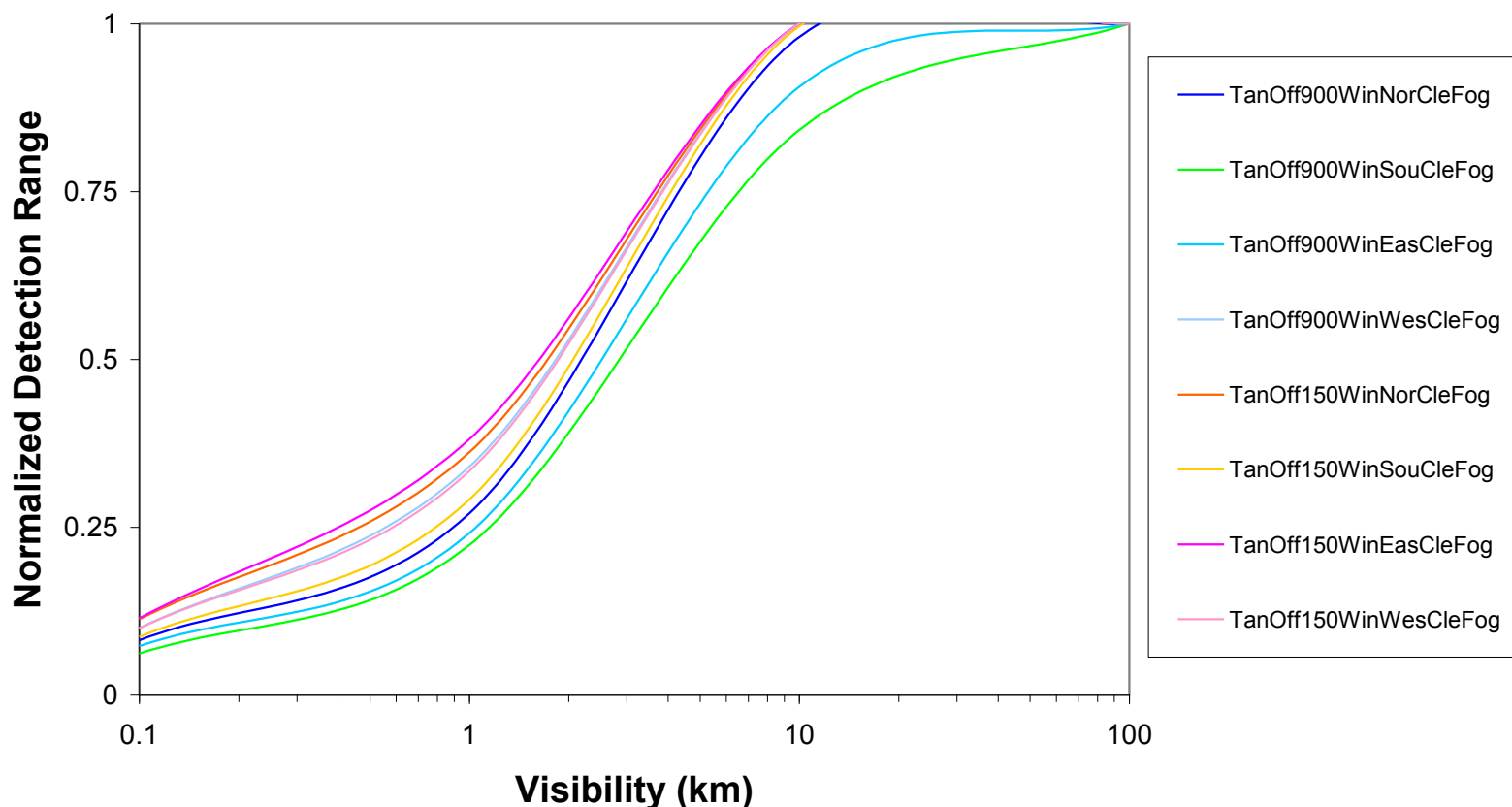
Legend:
- TanOff900WinNorCleFog
- TanOff900WinSouCleFog
- TanOff900WinEasCleFog
- TanOff900WinWesCleFog
- TanOff150WinNorCleFog
- TanOff150WinSouCleFog
- TanOff150WinEasCleFog
- TanOff150WinWesCleFog

Y-axis: **Normalized Detection Range**
X-axis: **Visibility (km)**
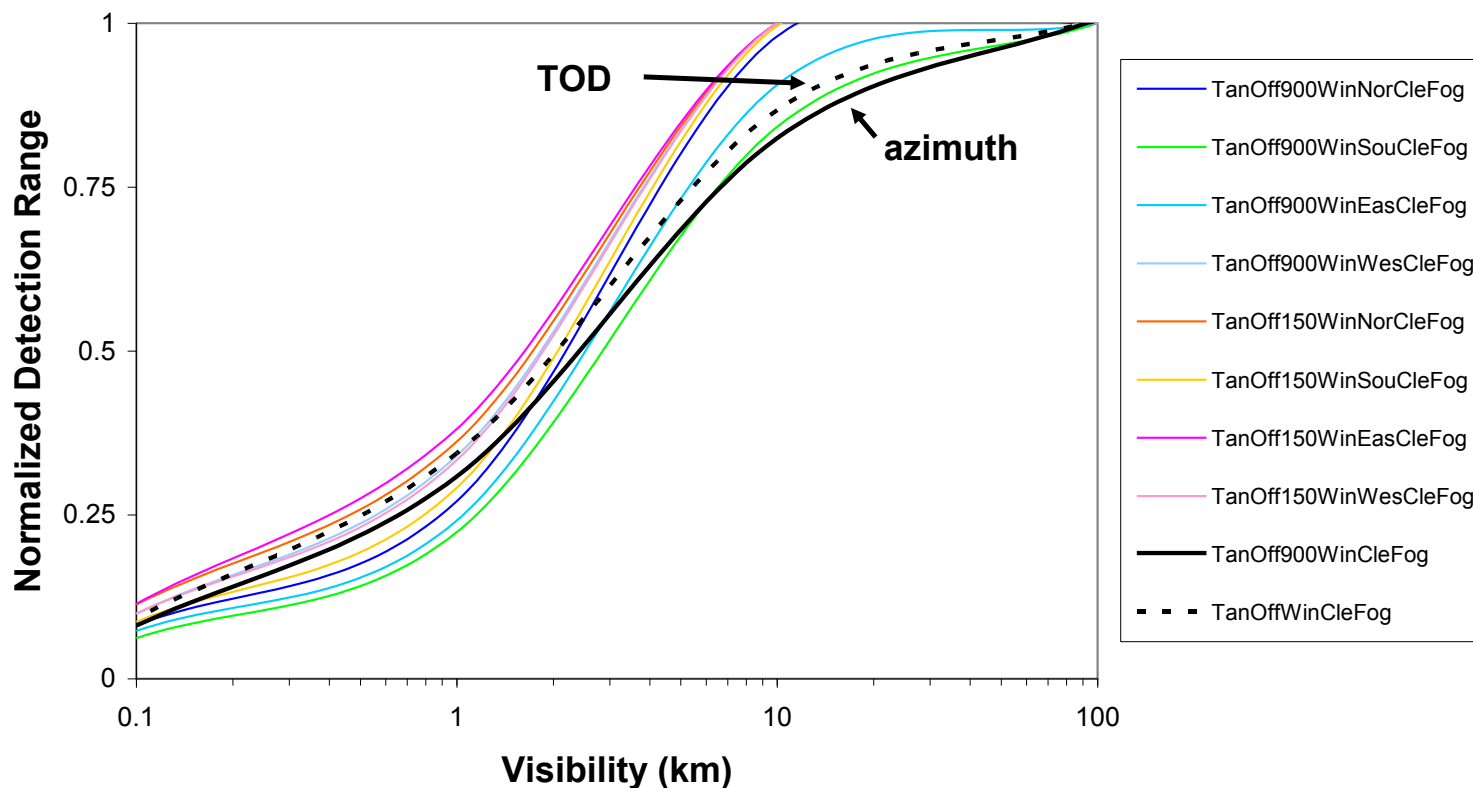
NFOV, Fog, Off Tank under cloudless skies, Winter
f(TOD & Azimuth)
(average over: sensors & locations)

**NFOV, Fog, Off Tank under cloudless skies, Winter
(average over: TOD, azimuth, sensors & locations)**

$$R = 66.59 - 21.59 \; \ln(Vis) - 2.57 \; \ln(Vis)^2 + 0.90 \; \ln(Vis)^3$$

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Helicopters

Helicopter Accidents Related to Weather
National Transportation Safety Board (NTSD)

PART 91 NTSB WEATHER RELATED ACCIDENTS BY WEATHER CONDITION
1994-2003

17,129 PART 91 ACCIDENTS

WEATHER RELATED 21%

NON-WEATHER RELATED 79%

WIND 51.0%

VISIBILITY/CEILING 19.8%

OTHER 0.1%

WINDSHEAR 1.2%

THUNDERSTORM 1.9%

PRECIPITATION 4.2%

DENSITY ALTITUDE 7.0%

ICING 7.1%

TURBULENCE 7.5%

Between 1994 and 2003, there were 19,562† aircraft accidents, involving 19,823 aircraft, of which 17,129 were conducted under FAR Part 91. Weather was a contributing cause or factor in 3,617 of the Part 91 accidents. This chart identifies the breakout of Part 91 weather related accidents according to the weather condition(s) involved in the event.
† Accidents include final reports only where causal factors were identified.
§ A single accident may involve multiple weather conditions.

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

PART 135 NTSB WEATHER RELATED ACCIDENTS BY WEATHER CONDITION
1994-2003

831 PART 135 ACCIDENTS

NON-WEATHER RELATED 69.1%
WEATHER RELATED 30.9%

VISIBILITY/CEILING 39.1%
WIND 26.6%
PRECIPITATION 11.0%
ICING 10.0%
TURBULENCE 7.4%
DENSITY ALTITUDE 4.1%
THUNDERSTORM 1.3%
WINDSHEAR 0.3%
OTHER 0.3%

Between 1994 and 2003, there were 19,562† aircraft accidents, involving 19,823 aircraft, of which 831 were conducted under FAR Part 135. Weather was a contributing cause or factor in 257 of the Part 135 accidents. This chart identifies the breakout of Part 135 weather related accidents according to the weather condition(s) involved in the event.
† Accidents include final reports only where causal factors were identified.
§ A single accident may involve multiple weather conditions.

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Approved For Public Release; Distribution Unlimited

Naval helicopter accident data obtained from Master's thesis

Percent Of Weather Groups For Weather Related Mishaps

- Thunderstorm 3%
- Combined Sea State 5%
- Density Altitude 5%
- Precipitation 12%
- Wind Related 16%
- Icing 3%
- Turbulence 2%
- Vis Related 54%
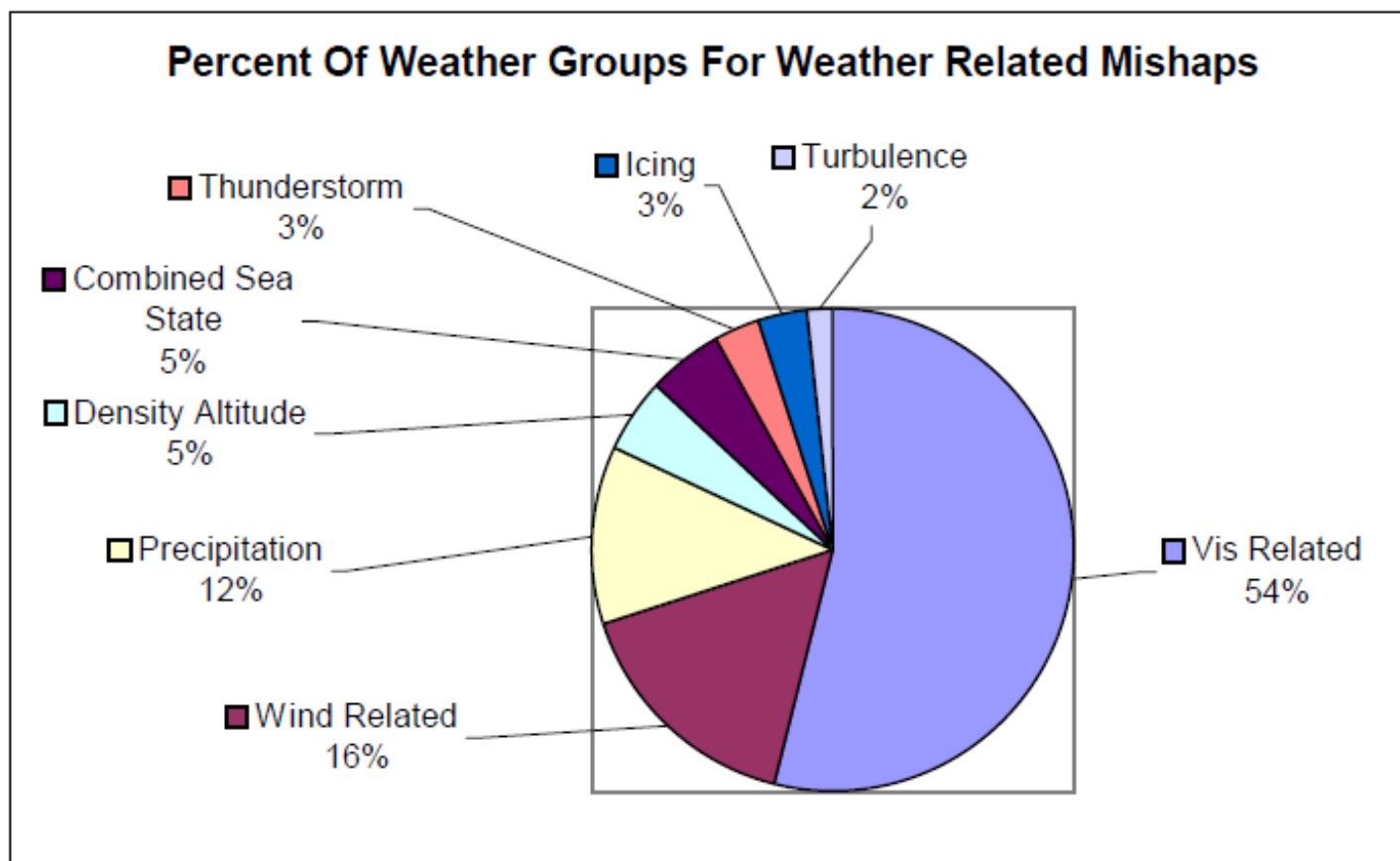
Concatenation of NTSB and Navy data

Source\ Quantity	Part 91	On-demand Part 135	Navy
No. aircraft accidents	1758	74	395
No. helicopter accidents	197	27	104
% helicopter accidents	11	36.5	26
No. environmental accidents	754	-	-
No. environmental accidents due to weather**	357	-	-
Percent environment accidents due to weather	47	-	-
Percent helicopter accidents w/in environment	36	-	-
Percent weather related accidents for fleet (all aircraft)	21	30.9	12
% of all weather related helicopter accidents	16.9	27.3	(18)
% of weather related helicopter accidents	1.9	9.9	(5)

Wargamers & commanders who have access to current weather conditions →

Mission planners using long-range forecasts.

Percent helicopter accidents by weather condition for command ($A_{w\text{-}cmd}$) and mission planning ($A_{w\text{-}mp}$) purposes. Includes detailed effects of visibility/ceiling and wind conditions.

Weather Condition	$A_{w\text{-}cmd}$ (%)		$A_{w\text{-}mp}$ (%)	
Visibility/Ceiling	Low ceiling	1.4	Low ceiling	0.4
	Fog	1.1	Fog	0.3
	Clouds	0.6	Clouds	< 0.2
	Obscuration	0.3	Obscuration	< 0.1
	Haze/smoke	0.1	Haze/smoke	< 0.1
	Whiteout	0.1	Whiteout	< 0.1
	Below approach/ landing minimums	0.1	Below approach/ landing minimums	< 0.1
	Sand/dust storm	< 0.1	Sand/dust storm	< 0.1
Wind	Crosswind	3.0	Crosswind	0.8
	Gusts	2.5	Gusts	0.7
	Tailwind	1.5	Tailwind	0.4
	High wind	0.7	High wind	0.2
	Unfavorable wind	0.4	Unfavorable wind	0.1
	Variable wind	0.3	Variable wind	< 0.1
	Sudden windshift	0.2	Sudden windshift	< 0.1
	Dust devil/ whirlwind	0.1	Dust devil/ Whirlwind	< 0.1

| Weather Condition	$A_{w\text{-}cmd}$ (%)	$A_{w\text{-}mp}$ (%)
Turbulence	1.7	0.5
Density altitude	1.3	0.4
Icing	1.3	0.4
Precipitation	0.8	0.2
Thunderstorm	0.3	0.1
Windshear	0.2	< 0.1
Other	0.0	0.0
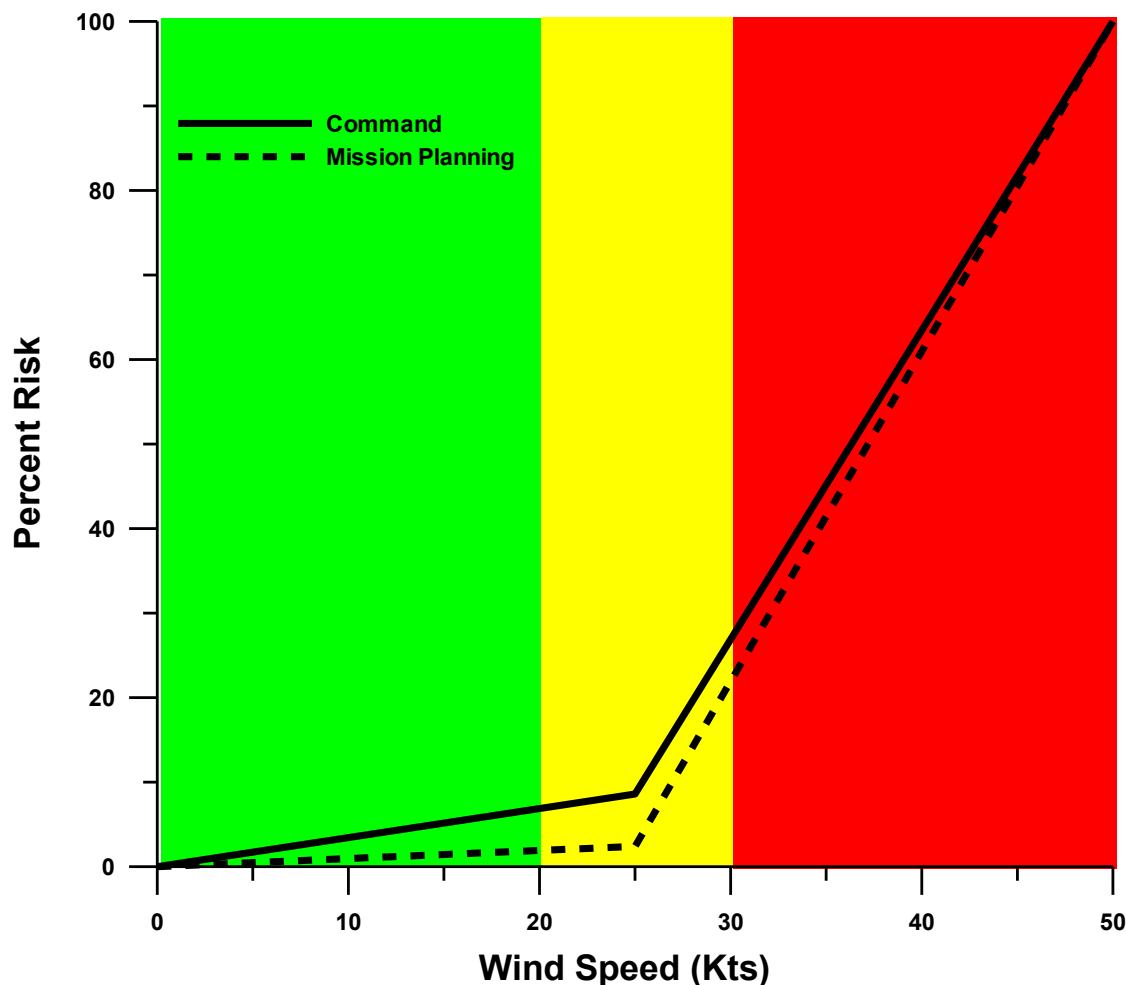
Piecewise linear curves for weather-related helicopter risk for command and mission planning purposes

Cold weather personnel equipment and manual tasks

**Effect of temperature on Army personnel manual and equipment tasks***
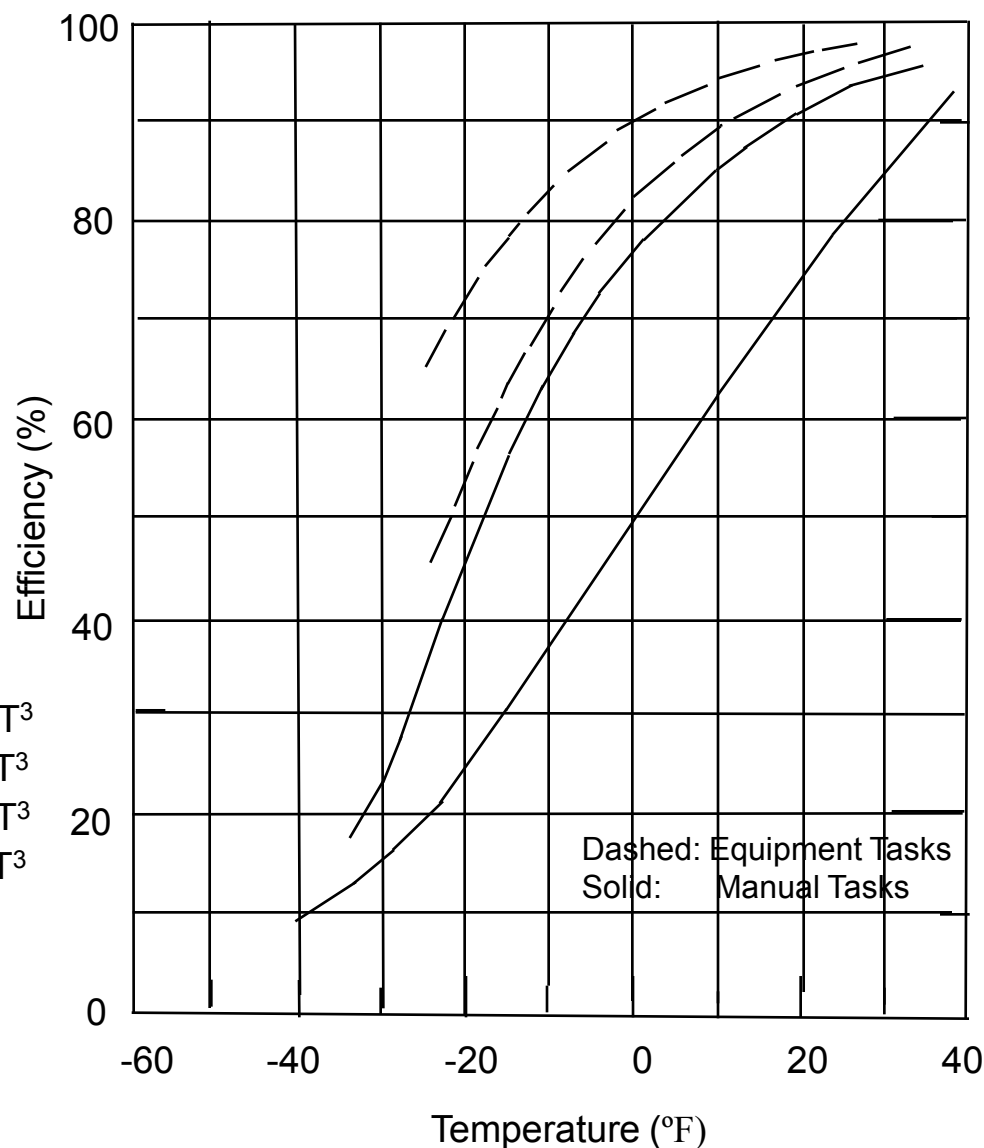
$Eff_{upr-equip} = 90.101 + 0.5144\ T - 0.0151\ T^2 + 0.0003\ T^3$

$Eff_{lwr-equip} = 81.971 + 0.9167\ T - 0.0202\ T^2 + 0.0002\ T^3$

$Eff_{upr-man} = 76.345 + 1.0777\ T - 0.0192\ T^2 + 0.0001\ T^3$

$Eff_{lwr-man} = 49.315 + 1.3158\ T + 0.0014\ T^2 - 0.0002\ T^3$

* Notes for Cold Weather Military Operations, P.W. Richmond (Ed), CRREL-SR-91-30, 1991.

Dashed: Equipment Tasks
Solid: Manual Tasks

Efficiency (%)

Temperature (ºF)

Boundaries determined by 25%/75% criteria
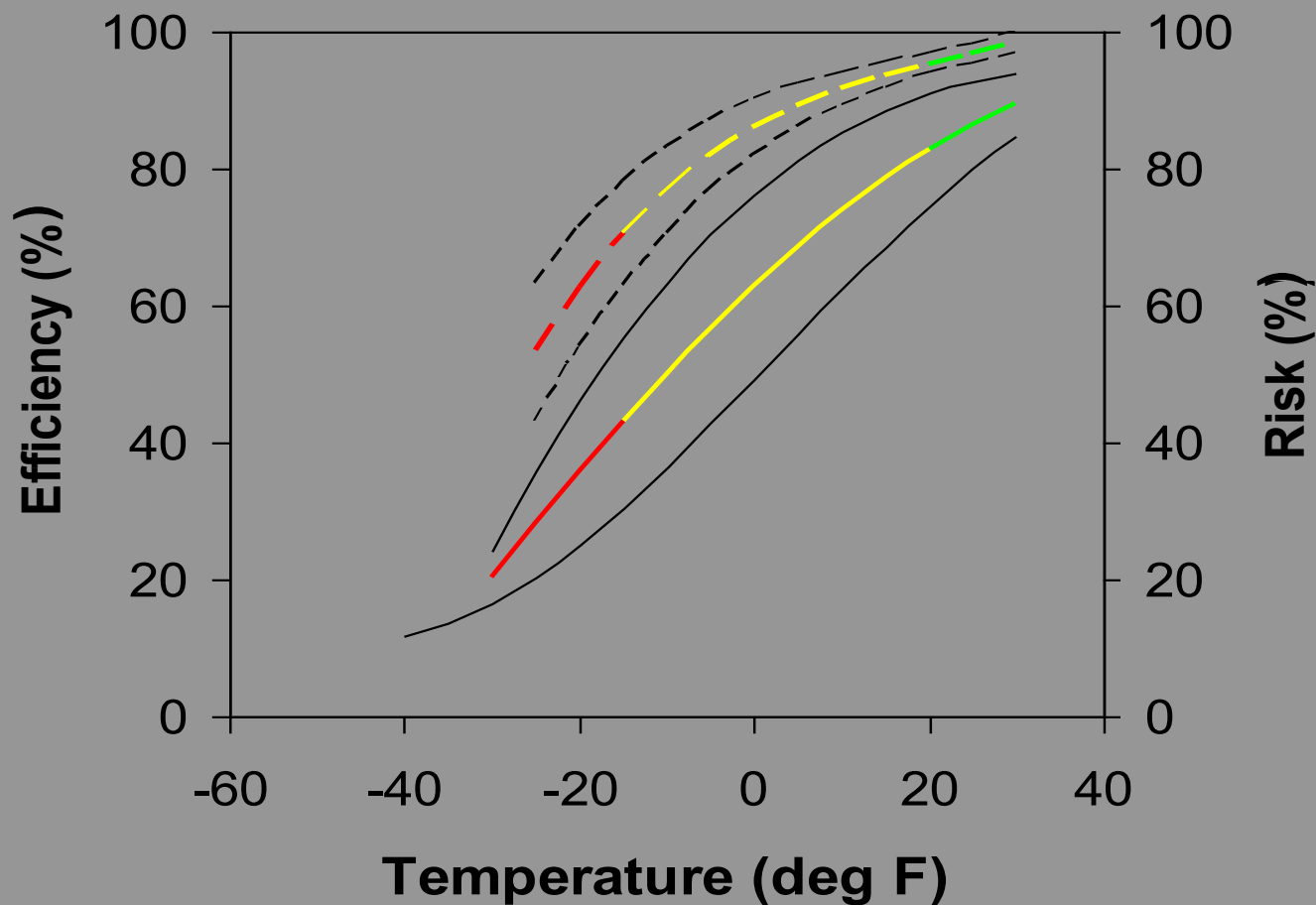
$R_E = 86.036 + 0.7156\ T - 0.0177\ T^2 + 0.00025\ T^3$

$R_M = 62.83 + 1.1968\ T - 0.0089\ T^2 - 0.00005\ T^3$

?

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CISD/Battlefield Environment Division
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White Sands Missile Range, NM 88002-5501

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