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Author

P. Tikusis and A.A. Keefe

Approved by

K. Hendy

Head / Simulation Modelling Acquisition Rehearsal Training Section

Approved for release by

K.M. Sutton

Chair / Document Review and Library Committee

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Abstract

The Cold Exposure Survival Model (CESM) was originally developed as a decision aid for Search and Rescue (SAR) to predict times to the limits of cognitive function and survival (from lethal hypothermia) under conditions of cold exposure. Its predictions are deterministic based on an individual's physical characteristics, exposure conditions, and clothing worn. In many situations, these details are unknown making it difficult to apply CESM with certainty. An algorithm is herein described that yields stochastic predictions of survival time (ST) based on gender and an age range without specification of the casualty's weight and height. Another concern of SAR operators is the ability of water-immersed survivors to self-board a life raft. Baseline data of boarding performance were used to generate an algorithm to predict the success/failure rate of self-boarding. The resultant outputs of these two algorithms, expressed as percentiles of ST and time limit of successfully boarding a life raft against exposure time, should markedly augment the use of the revised CESM as a SAR decision aid.

Keywords: water immersion, survival probability, sea survival, Monte Carlo simulation

Résumé

Le Modèle de survie à l'exposition au froid (MSEF) a été mis au point, à l'origine, pour servir d'outil d'aide à la décision aux équipes de R-S afin de leur permettre d'estimer les pertes de fonctions cognitives et le temps de survie (précédant l'hypothermie létale) lors d'une exposition au froid. Les prévisions du MSEF sont déterministes, fondées sur les caractéristiques physiques de la victime, les conditions d'exposition et les vêtements portés. Dans de nombreuses situations, ces informations ne sont pas connues, ce qui rend le MSEF difficilement applicable. On a donc recours à un algorithme qui fournit des prévisions stochastiques du temps de survie (TS) à partir du sexe et d'une plage d'âge, sans précision concernant le poids et la taille des victimes. Une autre préoccupation des spécialistes de R-S est la capacité des survivants à une immersion en eau froide de monter à bord d'un radeau de sauvetage par eux-mêmes. Les données de référence sur la capacité des personnes à monter sans aide à bord d'un radeau ont été utilisées pour générer un algorithme qui prédit le taux de succès ou d'échec relatif. Les résultats fournis par ces deux algorithmes, exprimés en centile du temps de survie et du temps maximum pour parvenir à monter à bord d'un radeau de sauvetage, par rapport à la durée d'exposition au froid, devraient accroître de façon marquée l'utilisation du MSEF révisé comme outil d'aide à la décision.

Mots clés : immersion dans l'eau, probabilité de survie, survie en mer, simulation Monte Carlo.

Executive summary

The Cold Exposure Survival Model (CESM) was originally developed to predict the survival time (ST; time to lethal hypothermia) of individuals exposed to cold for a specific set of inputs. Casualty information such as age, weight, and height, however, are often not known making it difficult to apply CESM with certainty. Through a Monte-Carlo simulation, stochastic predictions that incorporate the approximate age range of the casualty(ies) can be made and subsequently expressed as a distribution of survival times. For example, predicted times to 95, 50, and 5% survival outcomes can be interpreted as best to worst cases, respectively, in a revised CESM. This optional shift from a deterministic to probabilistic determination of ST can be applied to a single casualty or a group.

In many survival situations, considerable demands are placed on both the casualty and rescuer. Although advances in Search and Rescue (SAR) technologies allow for a rapid response, the casualty's state of self-help might impact on their survival outcome. A current concern of SAR operators is the ability of water-immersed survivors to self-board a life raft. Experimental data on this ability were collated to formulate an algorithm for predicting the time to failure for self-boarding as a function of the time spent in the water. Using a similar modelling construct as applied for the stochastic prediction of ST, percentiles of the probability of successful life raft boarding are presented through a revised CESM. Factors such as the loss of muscle strength due to cooling and the weight of wet clothing are also accounted for.

The input interface of CESM (v3.0) has been reconfigured to accept either a specific age or range of age. If the former, then specific values of the individual's weight and height must be declared; if the latter, then these characteristics are generated randomly, but rationally. The user is still expected to input specific environmental conditions and the clothing worn by the casualty(ies). The output of CESM v3.0 is a deterministic prediction of ST if inputs are specific, otherwise a distribution of ST (and failure times to self-board a life raft, if pertinent) will be displayed. These changes in CESM v3.0 should markedly augment the use of the model as a SAR decision aid.

Sommaire

Le Modèle de survie à l'exposition au froid (MSEF) a été mis au point, à l'origine, pour permettre d'estimer le temps de survie (TS : temps précédant l'hypothermie létale) des personnes exposées au froid, compte tenu d'un ensemble d'intrants spécifiques. Les renseignements sur les victimes, tels que l'âge, le poids et la taille, sont souvent inconnus, ce qui rend le MSEF difficilement applicable. Des prévisions stochastiques, qui incluent une plage d'âge approximative des victimes, peuvent être obtenues au moyen d'une simulation Monte Carlo et exprimées ultérieurement sous forme d'une distribution des temps de survie. Par exemple, des temps de survie prévus de 95 %, 50 % et 5 % peuvent être interprétés comme autant de scénarios, allant du meilleur au pire des cas, dans le MSEF révisé. Cette analyse facultative des données, d'une prévision du temps de survie déterministe à une prévision probabiliste, peut s'appliquer à une seule victime ou à un groupe de victimes.

Dans de nombreuses situations de survie, la victime et le sauveteur subissent des pressions considérables de part et d'autre. Bien que les percées dans les technologies de R-S permettent une intervention rapide, la débrouillardise des victimes peut avoir une incidence sur leurs chances de survie. La capacité des survivants d'une immersion en eau froide de monter par eux-mêmes à bord d'un radeau de sauvetage préoccupe actuellement les spécialistes de R-S. Les données expérimentales en ce qui concerne cette capacité ont été colligées afin d'établir un algorithme pour prédire le délai après lequel il devient impossible pour la personne de monter par elle-même à bord d'un radeau en fonction du temps passé dans l'eau. Lorsqu'on utilise un concept de modélisation similaire, tel qu'appliqué à la prévision stochastique des TS, le MSEF révisé fournit les centiles de la probabilité de réussir à monter à bord du radeau de sauvetage. Des facteurs comme la perte de la force musculaire due au refroidissement du corps et au poids des vêtements mouillés sont également pris en compte.

L'interface du MSEF (v. 3.0) a été reconfigurée pour permettre l'entrée d'un âge ou d'une plage d'âge particulier. Dans le cas de l'entrée d'un âge, les valeurs relatives au poids et à la taille des personnes doivent être précisées; dans le cas de l'entrée d'une plage d'âge, ces valeurs sont générées de façon aléatoire mais rationnelle. L'utilisateur doit encore fournir les conditions environnementales spécifiques ainsi que les vêtements portés par la ou les victimes. Si les données entrées sont spécifiques, les prévisions sur les temps de survie fournies par le MSEF (v. 3.0) sont déterministes. Si les données ne sont pas spécifiques, une distribution des temps de survie (et le délai après lequel il devient impossible de monter sans aide à bord du radeau de sauvetage, le cas échéant) s'affiche. Les modifications apportées au MSEF (v. 3.0) devraient accroître de façon marquée l'utilisation de ce dernier comme outil d'aide à la décision.

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Background

The Cold Exposure Survival Model (CESM) presently provides a prediction of survival time for a specific set of inputs. Casualty information, however, is often uncertain (eg., age, body size, clothing, etc.) that are best dealt with by providing predictions using broad estimates. Through a Monte-Carlo simulation, stochastic predictions that incorporate a range of casualty inputs can be subsequently expressed as a distribution of survival times. Predicted times to 95%, 50%, and 5% survival outcomes, for example, can be interpreted as best to worst cases, respectively.

Survival situations also place considerable demands on both the casualty and rescuer. Although advances in Search and Rescue (SAR) technologies allow for a rapid response, the casualty's state of self-help might impact on their survival outcome. Previous improvements to CESM added predictions of arm/hand performance decrements due to body cooling (Tikuisis and Keefe 2001). These predictions are expressed in terms of hand dexterity, grip strength, and push-up performance. While informative, the relevance of these performance measures to rescue situations is unavoidably vague. Instead, performance predictions on specific self-help strength manoeuvres (eg., lifting oneself or others) would significantly improve the model's utility. Indeed, the ability of survivors to self-board a life raft is a concern of SAR operators. To implement this aspect in CESM, data on self-boarding must be collated and subsequently modelled.

This report outlines the development of stochastic and life raft boarding predictions, and their implementation in a revised CESM.

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Stochastic Prediction

Introduction

To conduct a stochastic prediction of survival time (ST), a sufficient number of predictions must be made using different randomized combinations of individual characteristics for each prediction. The resultant distribution of ST can then be expressed as percentiles of survival rate. Appropriate data must first be identified for this purpose and applied in a rationale manner. If unrestricted, random combinations of weight and height might yield unrealistic anthropometric profiles. Once a weight is selected, the coupling to height must be congruent, yet also randomized.

The randomization process outlined below will yield wide predictions from a range of inputs, whether applied to a group of casualties or to a single casualty whose specific characteristics are unknown. Randomizations will also be confined to the physical characteristics of weight (wt) and height (ht), based on gender and age. Randomizations will not be applied to the clothing worn by the casualty or to the environmental conditions; these will continue to be selected in CESM as specific inputs.

Data

Current data were obtained from two sources (Chamberland et al. 1998, SAE 2000) and combined to provide a broad representation of the adult population, as displayed in Table 1. The original data were censored to exclude males and females having weights in excess of 150 and 120 kg, respectively, and ages greater than 60 yr.

Table 1. Age and physical characteristics of adult (18 – 60 yr) population (see text for citations).

VARIABLE	MALES (N = 867)			FEMALES (N = 492)		
	mean ± SD	***range***	***median***	***mean ± SD***	***range***	***median***
age (yr)	33 ± 8	18-60	33	34 ± 9	18-60	33
weight (kg)	84.0 ± 14.5	48.8-148.3	82.2	66.0 ± 12.0	40.6-118.4	63.8
height (m)	1.77 ± 0.07	1.49-2.08	1.77	1.64 ± 0.06	1.38-1.88	1.63

The following regressions relating height to weight were obtained using these data (the quadratic form for female 'ht' did not improve the regression sufficiently for inclusion):

males: $$\mathrm{ht} = 1.3122 + 0.00804 \cdot \mathrm{wt} - 3.0356\mathrm{e}{-5} \cdot \mathrm{wt}^2, \qquad r = 0.54 \qquad \text{Eq. 1}$$

females: $$\mathrm{ht} = 1.5165 + 0.0018293 \cdot \mathrm{wt}, \qquad r = 0.34 \qquad \text{Eq. 2}$$

Randomization

Height, but not weight, is normally distributed, which is a pre-requisite for obtaining population percentiles of a variable. Given a mean value of a variable and its SD, the n^{th} percentile of that variable is obtained by invoking the normal inverse function. A normal distribution of weight can be obtained through a conversion to its natural logarithmic form [i.e., ln(wt)]. The mean ± SD of ln(wt) are 4.431 ± 0.168 and 4.190 ± 0.173 for males and females, respectively, and the SD for height are 0.07 and 0.06 for the data described above. The randomization of weight and height is outlined in the following steps, and an example is demonstrated further below.

Step 1. Select a gender (male or female) and age range (from 18 to 60 yr).

Step 2. An age is randomly selected within the range specified using a standard randomization routine.

Step 3. A random number (n) from 1 to 100 is generated to select the n^{th} percentile of ln(wt), which is then re-converted to weight.

Step 4. The 50^{th} percentile height associated with the randomly-generated weight is determined using either Eq. 1 or 2, depending on gender.

Step 5. Another random number from 1 to 100 is generated to select the n^{th} percentile of height, which is now coupled with the above-determined weight.

Example of the randomized selection of weight and height; underlined items are inputs and bold items are outputs (84.7 kg and 1.86 m are the final randomized coupled values):

Step 1. male <u>√</u> female _ ; age range: low <u>25</u> high <u>30</u>

Step 2. random age = **28**

Step 3. random number = **52**; 52^{nd} percentile of ln(wt) = **4.44**; weight = **84.7 kg**

Step 4. 50^{th} percentile height = **1.78 m** using Eq. 1

Step 5. random number = **91**; 91^{st} percentile of height = **1.86 m**

100 randomly-generated values of weight and height in various age ranges for each gender were compared (t-test) against the original data and not found to be different ($p > 0.05$).

Application

A distribution of ST can be obtained by applying CESM repeatedly to a sufficient number (eg., 100) of randomized weight-height combinations, as outlined above, for the gender and age range of interest. This is demonstrated through an example shown in Figure 1 involving neck-level immersion in heavy seas at 5 °C with casualties wearing a long-sleeved shirt, light sweater, and jacket. Figure 1 illustrates the predicted ST for 100 combinations of weight and height for both males and females from 18 to 60 yr old. The percentage of survivors begins at 75% because of the assumption that a certain number of water-immersed casualties will not survive the initial immersion due to cold shock, injury, or other lethal factor. This adjustment was introduced by Wissler (2003) and is adopted herein, as follows:

$$\text{initial survival \%} = 75 \quad \text{if } T_{water} \le 10°C$$
$$= 100 - 2.5 \cdot (20 - T_{water}) \quad \text{if } 10 < T_{water} < 20°C \qquad \text{Eq. 3}$$
$$= 100 \quad \text{if } T_{water} \ge 20°C$$

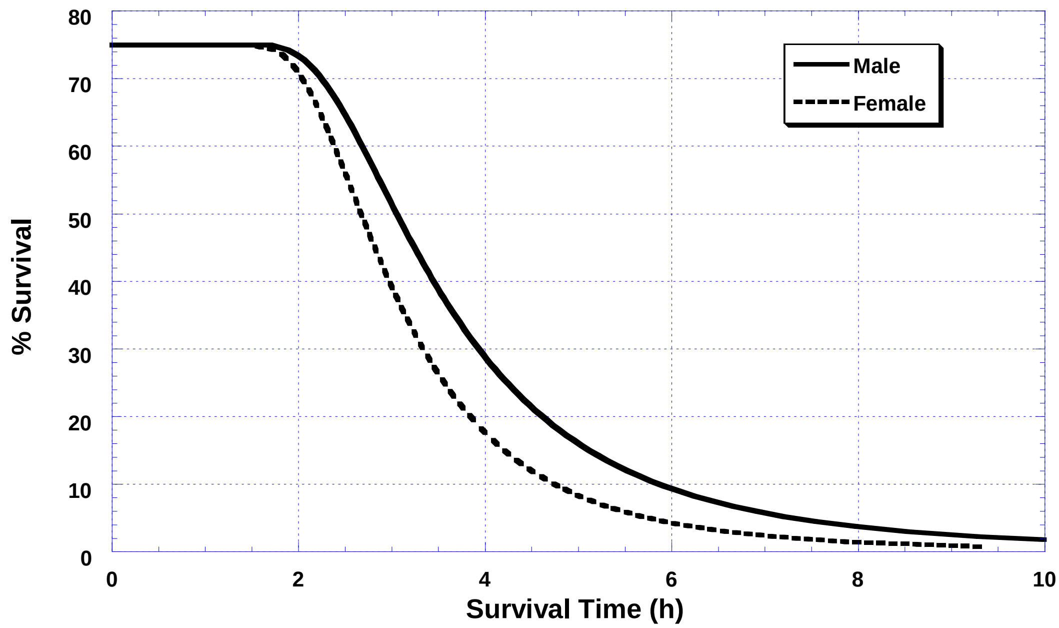

Figure 1. Predicted distribution of ST in hours for casualties neck-immersed in 5°C heavy seas and wearing a long-sleeved shirt, light sweater, and jacket.

Since ST is not normally distributed, its values must be log-transferred to obtain percentiles using the same procedure as applied for weight. Table 2 shows the resultant percentiles of ST for the 75% of casualties that survived the initial immersion in the above example. That is, the 50th percentile of ST is 3.6 h for males and 3.1 h for females, excluding those that perished during the initial immersion. That females have a lower predicted ST is due to various anthropometric and metabolic differences described in Keefe and Tikuisis (2004).

Table 2. Percentiles of ST of survivors beyond the initial immersion for conditions of Figure 1.

GENDER	VARIABLE	% SURVIVAL				
		95	***75***	***50***	***25***	***5***
Male	***ln(ST)***	0.776	1.038	1.269	1.553	2.076
	ST (h)	2.2	2.8	3.6	4.7	8.0
Female	***ln(ST)***	0.684	0.913	1.117	1.367	1.827
	ST (h)	2.0	2.5	3.1	3.9	6.2

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Life Raft Self-Boarding Prediction

Introduction

Aside from personal physical characteristics, external factors such as life raft design, water temperature, wind, and sea state impact on a person's ability to self-board a life raft (Brooks et al. 1997, 1998). No comprehensive study of all these factors has been made to assist in the prediction of successful boarding. In response, we have conducted a baseline study of the personal factors that facilitate self-boarding an inflated double-tube life raft (Tikuisis et al. 2005). Males were generally able to board the life raft over the side without aids (ramp or ladder) more quickly and with less effort than females, due primarily to their predominance in strength and height.

This study also determined the maximum load that individuals can be burdened with when self-boarding a life raft. The rationale for determining this load was to establish an individual's 'reserve' capacity, expressed as a percentage of additional weight that could be carried beyond the individual's own body weight. In cold water, this capacity will diminish with muscle cooling. It is theorized that when individuals have lost their reserve capacity, they would be at their threshold of just being able to self-board, and the time that this occurs could be predicted using a model of body cooling (Tikuisis 1997, Tikuisis and Keefe 2001). Differences in the reserve capacity were found between genders and with age (Tikuisis et al. 2005). The results of the life raft study are applied below for predicting the success/failure rate of self-boarding a life raft over the side (i.e., without aids).

Initial Failure Rate

Due to an innate inability, there is a probability that an individual cannot self-board a life raft even before any muscle cooling occurs. The probability of this initial failure rate can be generalized from the results of the life raft study in terms of gender, body mass index (BMI), and age, as follows.

Step 1. Using the randomization procedure outlined earlier (see **Randomization**), weight and height are generated for the gender and age range of interest.

Step 2. The initial failure rates are set at 25% for males > 40 yr, and 25 and 50% for females ≤ 40 and > 40 yr, respectively.

Step 3. The initial failure rate is then further increased, linearly as BMI increases from 28 to 38 $kg \cdot m^{-2}$, at which point it reaches 100%.

Step 4. An additional adjustment due to age is applied such that the initial failure rate, if less than 100%, increases sigmoidally from 40 to 60 yr, at which point it reaches 100%.

The latter two steps are implemented arbitrarily to account for difficulties that very large and older individuals would likely encounter, but could not be addressed directly by the life raft study. Example of the procedure outlined above:

Step 1. 45 yr old male, 85.6 kg and 1.72 m leads to BMI = 33.0 $kg \cdot m^{-2}$

Step 2. initial failure rate = 25%

Step 3. BMI adjusted initial failure rate = 63%

Step 4. additional age adjusted initial failure rate = 65%

The application of 100 randomly-generated combinations of weight and height for each gender between 18 and 60 yr (as conducted earlier under **Stochastic Prediction**) generated initial self-boarding failure rates of 36.5 and 49.8% for males and females, respectively. The predicted time to failure for the remaining casualties follows.

Time to Failure

Based on the results of the life raft boarding study (Tikuisis et al. 2005), the reserve capacity of males ≤ 40 yr is set at 15.4 and 20.5% for body weights greater and less than the mean weight, respectively. The reserve capacity for males > 40 yr is set at 10.9%, and for females is set at 12.6 and 8.8% for ages ≤ 26 and > 26 yr, respectively. The SD of the reserve capacities is set at 5.5 and 6.1% for males and females, respectively, for all ages.

Since the reserve capacities were established under semi-nude conditions, a reduction should be made to account for wet clothing worn by the immersed individual. Laboratory measurements of completely wet clothing of the upper body, expressed as a percentage of the individual's body weight, are listed in Table 3 for the various clothing options in CESM. The root of the sum of squares of wet weights of the garments worn is used to determine overall wet weight when multiple garments are selected. The final clothing burden (% of body weight) is then subtracted from the initial estimate of the reserve capacity.

Once the final or *in situ* reserve capacity has been established, the body-cooling model (Tikuisis and Keefe 2001) is applied to predict the change in the mean muscle temperature of the arm (ΔT) as a function of immersion time in water. The resultant decrease in muscle strength is predicted using:

$$\text{strength} = \text{strength}_{\text{max}} \cdot Q_{10}^{\Delta T/10} \qquad \text{Eq. 4}$$

where Q_{10} defines the factor of change in muscle strength for each 10°C change in mean muscle temperature, herein assumed to be 1.4 (Tikuisis and Keefe 2001), and strength_{max} is based on the reserve capacity given by:

$$\text{strength}_{\text{max}}(\%) = 100 + \text{reserve}(\%) \qquad \text{Eq. 5}$$

Table 3. Wet weight of various clothing options in CESM where ug refers to undergarment; values for the dry suit vary according to the amount of clothing wetness.

GARMENT	WET WEIGHT (% OF BODY WEIGHT)	ENSEMBLE	WET WEIGHT (% OF BODY WEIGHT)
t-shirt	0.7	light wetsuit	3.9
light vest or shell	0.5	heavy wetsuit	5.6
long-sleeved shirt	1.0	snowmobile suit	10.0
light sweater	2.6	coverall + light ug	2.9
heavy sweater	3.8	coverall + medium ug	4.6
jacket	1.9	coverall + heavy ug	8.6
light parka	6.6	dry suit + light ug	6.3 - 8.4
heavy parka	8.2	coverall + medium ug	6.6 -10.1
		coverall + heavy ug	6.9 – 14.1

According to the hypothesis stated earlier, immersed individuals are predicted to be at their threshold of just boarding a life raft when their strength reaches 100% (i.e., the capacity to self-board only their own body weight). Therefore, by substituting Eqs. 5 into Eq. 4 with strength = 100%, the following resultant expression can be used to determine the decrease in the mean muscle temperature of the arm corresponding to the body weight threshold.

$$100 = (100 + \text{reserve}) \cdot Q_{10}^{\Delta T/10}$$

or

$$\Delta T = 10 \cdot \ln\left[100/(100 + \text{reserve})\right] / \ln\left(Q_{10}\right) \qquad \text{Eq. 6}$$

The time to failure (t_{fail}) of self-boarding a life raft can then be extracted from the body cooling model embedded within CESM. The predicted t_{fail} must be further modified according to the predicted rate of successful initial entry (%success); that is, entry attempts after a period of immersion are only meaningful if the individual was capable of boarding the life raft at the start of the immersion. Hence, the mean-weighted time to failure ($\bar{t}_{fail}$) is given by:

$$\bar{t}_{fail} = \frac{\sum_{m=1}^{100} \%\text{success}_m \cdot t_{fail,m}}{\sum_{m=1}^{100} \%\text{success}_m} \qquad \text{Eq. 7}$$

And its variance is given by:

$$SD = \sqrt{\frac{\sum_{m=1}^{100} \%success_m \cdot t_{fail,m}^2 - \left(\sum_{m=1}^{100} \%success_m \cdot t_{fail}\right)^2 / \sum_{m=1}^{100} \%success_m}{\sum_{m=1}^{100} \%success_m - 1}} \qquad \text{Eq. 8}$$

and is based on 100 randomized samples.

The following steps outline the determination of the distribution of t_{fail} for individuals that are initially able to self-board a life raft, as a continuation of the previous steps (see **Initial Failure Rate**).

Step 5. A random number (n) from 1 to 100 is generated to select the n^{th} percentile of the reserve capacity.

Step 6. The reduction in the reserve capacity due to wet clothing is applied through Table 3. (note % = $\sqrt{\text{sum of squares of garment values}}$).

Step 7. The time to failure to self-board the life raft is calculated using Eq. 6 and the body-cooling model (Tikuisis and Keefe 2001).

Step 8. The mean-weighted t_{fail} is calculated using Eq. 7 after 100 predictions of t_{fail} are collated.

Example of the procedure outlined above for males from 18 to 60 yr old immersed in 10°C heavy seas wearing a long-sleeved shirt, light sweater, and jacket; underlined items are inputs and bold items are outputs:

Step 5. age = 42 yr; weight = 84.1 kg; random number = 77; random reserve capacity = 14.9% (of body weight)

Step 6. reduction in reserve capacity = $\sqrt{1.02 + 2.62 + 1.92}$ = 3.4%; final reserve capacity = 11.5%

Step 7. predicted change in mean muscle temperature of the arm to reach the threshold of self-boarding = -3.2°C; time to failure = 23 min.

Step 8. the mean-weighted ± SD t_{fail} for N = 100 are 28.3 and 15.2 min, respectively

The distribution of mean-weighted t_{fail} is shown in Figure 2 assuming a normal distribution, and adjustments for the percentage of individuals that do not survive the initial immersion (75%), and those that survive the initial immersion and are also able to self-board the life raft (56.3%). For example, given that 10 males were suddenly immersed in water under the conditions of Figure 2, then 7 to 8 would be predicted to survive the initial immersion, but of these, only 56% or 4 survivors would be able to initially self-board the life raft. The predicted number of survivors still capable of self-boarding reduces to 3, 2, and 1 after 20, 30, and 40 minutes of immersion, respectively.

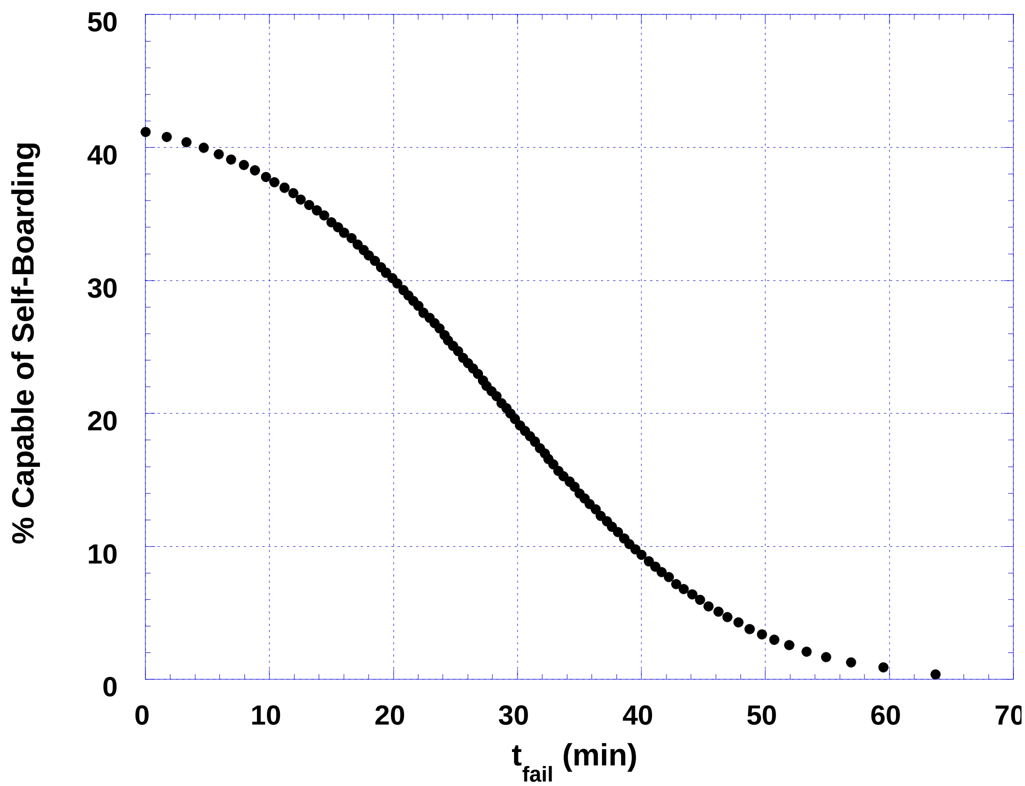

Figure 2. Predicted distribution of life raft self-boarding time limits, in minutesfor males neck-immersed in 10°C heavy seas and wearing a long-sleeved shirt, light sweater, and jacket.

Conclusion

It is emphasized that the present findings pertain to a single design life raft under calm conditions. The number of successful/failed boarding attempts can be expected to vary not only with different life raft designs, but also under less than optimal sea states. Indeed, turbulent wave conditions markedly escalate the challenge of boarding a life raft, even with aids (Ritter 2000). The present model predictions should, therefore, be viewed as somewhat liberal. Further research is required to validate the predictions under turbulent, cold sea conditions.

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Revised CESM

Revisions to CESM's algorithm necessitate modification of the user interface to accommodate changes to the model input and output requirements. Figure 3 illustrates the interface of the current, deterministic version of CESM (v2.2).

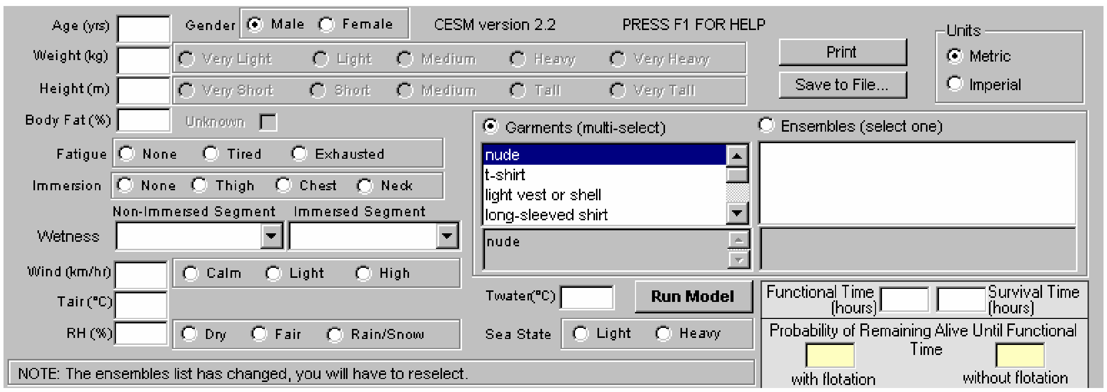


Figure 3. Interface of the current, deterministic version of CESM (v2.2)

While the stochastic predictions described earlier are anticipated to be widely used, it is desirable to retain a deterministic capability for incidents where specific casualty information is known. It is therefore proposed that both versions of the model are available via a button option select. As the terms "stochastic/probabilistic" and "deterministic" are likely unfamiliar to most users, they will be replaced by "probability" and "single value" to provide a more meaningful interface, as displayed in Figure 4.

Figure 4. User selection of probabalistic (probability) or deterministic (single value) predictions.

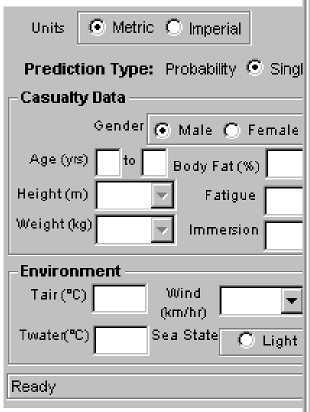
While the bulk of the CESM interface is common to both versions, there are several differences to the model input and output parameters, as summarized in Table 4.

Table 4. Differences between input and output parameters of the two versions of CESM.

PARAMETER	DETERMINISTIC (V2.2)	PROBABILISTIC (V3.0)
Input		
Age	Single value	Single value or range
Height	Single value	Not required
Weight	Single value	Not required
Output		
Critical time	Survival time (ST) and functional time (FT)	5, 25, 50, 75 and 95^{th} ST percentile, 50^{th} percentile for FT
Windchill (non-immersed)	Not available	Auto-displayed when risk is present
Life Raft Boarding	Not available	User-selected

Interface Accommodation Changes

Screen space available to CESM is limited since it is designed as component software, capable of residing within a larger application or standing alone within its own container. A simplified interface is necessary to accommodate the additional screen dialogs. An additional benefit from this would be the consolidation of related parameters and improved data entry flow, resulting in a more ergonomically desirable interface. Figure 5 illustrates these proposed changes to CESM. Anthropometric, environmental, and clothing parameters are logically grouped, while program execution, data output, and file management functions follow sequentially. Simplification of the entire interface is further achieved by changing the user selected option buttons to drop-down menus.



Figu

Additional gains in screen … the probabilities of survival that originated … et al., 1997). This decision was based … l beyond the initial immersion in cold …

Model Inputs

If the 'Single Value' optio … eight must be entered as specific inputs … on, two input boxes will appear to spec … and weights will then be internally ge … the age range. If a single casualty is involv … weight (otherwise 'Single Value' … ould be selected and th casualty's age ente … of height and weight values based on th … ays the input screen for CESM v3.0 wh … obability' option is selected.

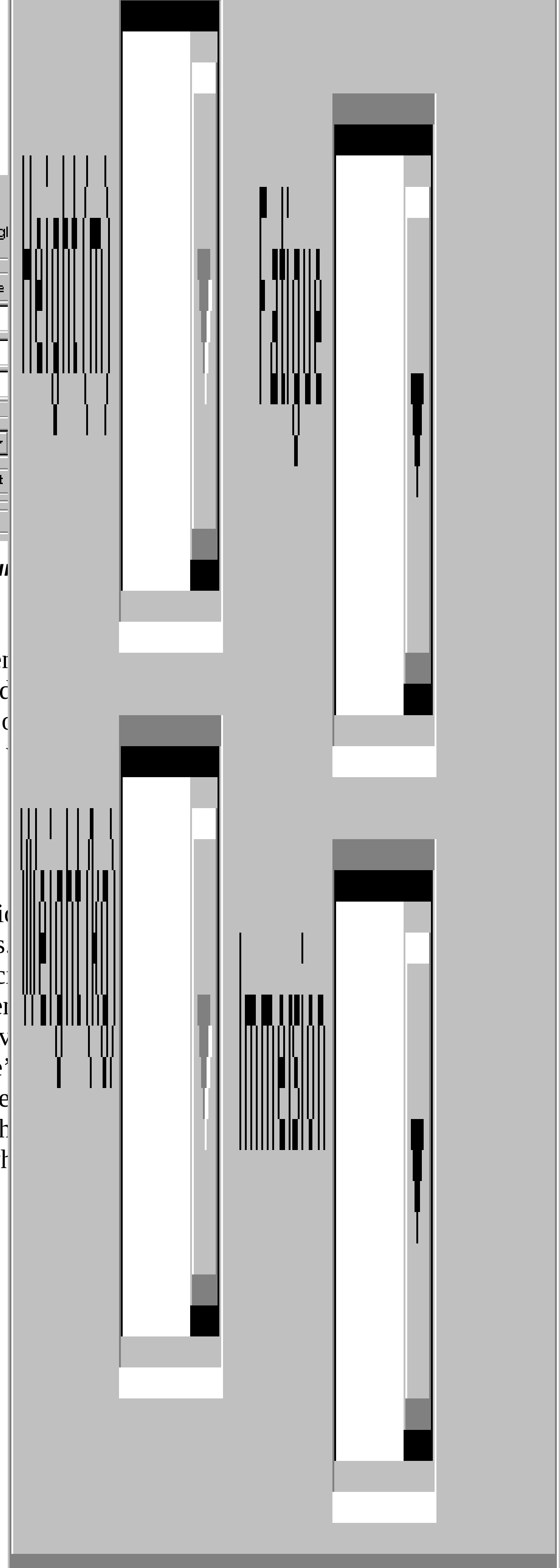


Figure 6. Inputs for CESM v3.0.

Model Output

As indicated in Table 4, the following three model outputs must be accommodated by the model interface: 1) survival and functional times, 2) risk of freezing, and 3) life raft boarding prediction.

Survival and Functional Times

To present the distributions of ST generated by the probabilistic calculation in a simple and meaningful way, five ST's covering the 95th to 5th percentile of survival (high to low chance) are displayed. For example, the ST of the 75th percentile for a group of casualties means that 75% of the group is predicted to still be alive at this time. If a single casualty were involved, then the 75th percentile would represent a 75% probability of surviving to this time. Functional time is only provided for the 50th percentile (i.e., one-half of casualties would be predicted to have lost their cognitive abilities by this point). Figure 7 illustrates the presentation of ST and FT outputs in CESM v3.0.

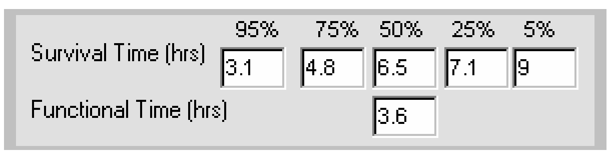


Figure 7. Example illustration of ST and FT output using CESM v3.0.

Risk of Freezing

To provide a more complete assessment of casualty status and risk to the rescuer, a risk of tissue freezing prediction, and time to freezing estimates for both the cheek and finger are calculated according to the methodology of Tikuisis and Keefe (2004). These data will be displayed only when the level of immersion is less than 100% (neck level), and a combination of wind speed and air temperature results in a possibility of freezing. If these conditions are not met, then the risk and time to freezing will not be displayed. Figure 8 illustrates the proposed appearance of the risk of freezing and freezing times for the finger and cheek in CESM v3.0.

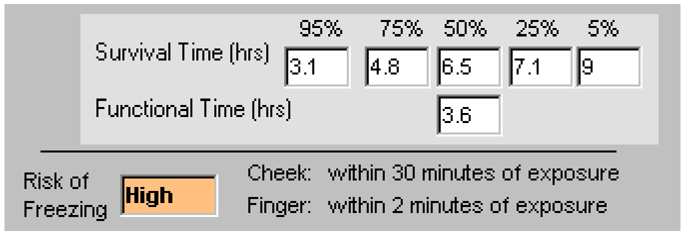


Figure 8. Example illustration of the risk of freezing and time to freezing estimates for the cheek and finger.

Life Raft Boarding

Life raft boarding calculations are computationally intensive and relevant to very specific casualty scenarios. Consequently, this prediction will only be calculated when requested by the user. As neck-level immersion is a further requisite for these calculations, a "Life Raft" check box will appear next to the "Immersion Level" whenever neck-level immersion is selected. Checking this box will enable the life raft boarding predictions (Figure 9).

Figure 9. Life raft boarding prediction option available when neck level immersion is selected.

Life raft boarding prediction times are presented in a manner similar to survival times such that ranges of immersion times (95% to 5% of casualties) denoting limits to successful boarding are calculated. As risk of freezing and life raft boarding estimates will never appear simultaneously due to their dependency on immersion level, the same screen space will be utilized to present these results (Figure 10)

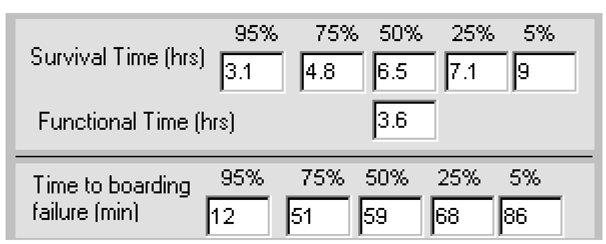


Figure 10. Example illustration of time to life raft boarding failure prediction output.

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List of symbols/abbreviations/acronyms/initialisms

CESM	Cold Exposure Survival Model
DND	Department of National Defence
SAR	Search and Rescue
BMI	body mass index ($kg \cdot m^{-2}$)
m	Metres
kg	kilogram
yr	year
min	minutes
h	hours
ht	height (m)
wt	weight (kg)
t_{fail}	time to failure (min) of self-boarding a life raft
$\bar{t}_{fail}$	mean weighted time to failure (min) of self-boarding a life raft
SD	standard deviation
T	temperature (°C)
ST	survival time (h)
FT	functional time (h)

Glossary

$Strength_{max}$	maximum muscle strength
%Success	predicted rate of successful entry
Q_{10}	factor of change for a 10°C change in tissue temperature

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(U) The Cold Exposure Survival Model (CESM) was originally developed as a decision aid for Search and Rescue (SAR) to predict times to the limits of cognitive function and survival (from lethal hypothermia) under conditions of cold exposure. Its predictions are deterministic based on an individual's physical characteristics, exposure conditions, and clothing worn. In many situations, these details are unknown making it difficult to apply CESM with certainty. An algorithm is herein described that yields stochastic predictions of survival time (ST) based on gender and an age range without specification of the casualty's weight and height. Another concern of SAR operators is the ability of water−immersed survivors to self−board a life raft. Baseline data of boarding performance were used to generate an algorithm to predict the success/failure rate of self−boarding. The resultant outputs of these two algorithms, expressed as percentiles of ST and time limit of successfully boarding a life raft against exposure time, should markedly augment the use of the revised CESM as a SAR decision aid.

(U) Le Modèle de survie à l'exposition au froid (MSEF) a été mis au point, à l'origine, pour servir d'outil d'aide à la décision aux équipes de R−S afin de leur permettre d'estimer les pertes de fonctions cognitives et le temps de survie (précédant l'hypothermie létale) lors d'une exposition au froid. Les prévisions du MSEF sont déterministes, fondées sur les caractéristiques physiques de la victime, les conditions d'exposition et les vêtements portés. Dans de nombreuses situations, ces informations ne sont pas connues, ce qui rend le MSEF difficilement applicable. On a donc recours à un algorithme qui fournit des prévisions stochastiques du temps de survie (TS) à partir du sexe et d'une plage d'âge, sans précision concernant le poids et la taille des victimes. Une autre préoccupation des spécialistes de R−S est la capacité des survivants à une immersion en eau froide de monter à bord d'un radeau de sauvetage par eux−mêmes. Les données de référence sur la capacité des personnes à monter sans aide à bord d'un radeau ont été utilisées pour générer un algorithme qui prédit le taux de succès ou d'échec relatif. Les résultats fournis par ces deux algorithmes, exprimés en centile du temps de survie et du temps maximum pour parvenir à monter à bord d'un radeau de sauvetage, par rapport à la durée d'exposition au froid, devraient accroître de façon marquée l'utilisation du MSEF révisé comme outil d'aide à la décision.

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(U) water immersion, survival probability, sea survival, Monte Carlo simulation

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