



TEMPSC Structural Design Basis Determination

Part 3 – Event Levels and Safety Margins

Prepared by **P A F A Consulting Engineers** for the
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This report part 3 covers the final Phase of a three Phase HSE funded study into the structural design basis for Totally Enclosed Motor Propelled Survival Craft (TEMPSC). Part 1 addresses Structural Design Basis Determination, Part 2 Design Events and Failure Capabilities. Emphasis is placed on typical TEMPSC that are currently in-service in the UK Sector of the North Sea, with the generic TEMPSC as a 50-man, Glass-fibre Reinforced Polymer (GRP), side-on davit-launched craft, stationed on a fixed steel platform. Such a craft would be typical of lifeboats installed in the early to mid 1980's and therefore designed and manufactured in accordance with the pre-1986 amendments to the 1974 Safety of Life at Sea (SOLAS) regulations. The objective of this third, and final, phase is to estimate the likelihood of the generic TEMPSC suffering structural failure during each of six design events, identified in phase 2 of this project, and quantifying the safety margin between the design load and estimated average strength of the TEMPSC.

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1. Summary

General:

This report part 3 covers the final Phase of a three Phase HSE funded study into the structural design basis for Totally Enclosed Motor Propelled Survival Craft (TEMPSC). Part 1 addresses Structural Design Basis Determination, Part 2 Design Events and Failure Capabilities. Emphasis is placed on typical TEMPSC that are currently in-service in the UK Sector of the North Sea, with the generic TEMPSC as a 50-man, Glass-fibre Reinforced Polymer (GRP), side-on davit-launched craft, stationed on a fixed steel platform. Such a craft would be typical of lifeboats installed in the early to mid 1980's and therefore designed and manufactured in accordance with the pre-1986 amendments to the 1974 Safety of Life at Sea (SOLAS) regulations. The objective of this third, and final, phase is to estimate the likelihood of the generic TEMPSC suffering structural failure during each of six design events, identified in phase 2 of this project, and quantifying the safety margin between the design load and estimated average strength of the TEMPSC.

Colliding with the platform during descent:

It is shown that the TEMPSC will not collide with a 1.0-m diameter member with sufficient force to fail the TEMPSC. Furthermore, there is little likelihood of such a collision occurring. A safety margin of 2 to 3 is estimated.

TEMPSC dropping into the sea:

It is estimated that a fully laden TEMPSC will exhibit structural failure if dropped by more than around 5 m. While such an event may occur around once every 150 years during an emergency evacuation, it is felt that this likelihood may increase to once every 3 years during trial launches and maintenance, due to their greater frequency.

TEMPSC and occupants overloading davits:

It is considered very unlikely that a well maintained TEMPSC could be damaged due to overload whilst in its davits. A safety margin of 9 is estimated between the fully-laden load and the ultimate failure strength of the davits.

TEMPSC complete immersion in water:

It is considered very unlikely that a TEMPSC could be damaged due to submergence since it would need to be 33 m underwater to fail. A safety margin of around 6.5 is estimated.

Damage to TEMPSC during towing:

It is considered very unlikely that a TEMPSC could be structurally damaged during towing due to water pressure on the bow but the towing connection could fail at extreme wave loads. A safety margin of around 1.0 appears appropriate.

Collision between TEMPSC and platform during escape:

In relatively moderate environmental conditions, wind and wave forces can cause the TEMPSC to collide with platform members. TEMPSC launched on the windward side of the platform into moderate seas would only occur in emergency situations. Consequently, it is estimated that the likelihood of such an event would be around once in 15 – 20 years.

The following observations are made:

- Due to the lack of industry verification of material data, in particular, a number of assumptions were necessary when carrying out the damage assessment. Therefore, the assumptions made in this report need to be independently reviewed and verified.
- Data relating to TEMPSC incidents worldwide and in the UK sector of the North Sea be collated and compared to the estimates made in this project.

- The impact forces and energies in the three more likely accident scenarios be related to forces and accelerations on the evacuees, so that personnel injuries can be quantified.
- A risk analysis be performed to generate improved data on the likelihood of such events occurring and the most cost-effective method of mitigation of such events.

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3. Glossary

GRP	Glass-fibre Reinforced Polymer Resin
HSE	United Kingdom Health and Safety Executive
Set-back	The degree to which the stern of a TEMPSC moves towards the installation reference its stowed position as the TEMPSC is lowered and manoeuvred into the desired escape direction.
SOLAS	IMO Safety of Life at Sea Convention (for Life-saving Appliances)
SWL	Still Water Level
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
Wash-back	The degree to which the TEMPSC moves towards the installation by the effects of wind and waves after splashdown.

4. Introduction

Since the Piper Alpha disaster (1988) and the subsequent report by Lord Cullen (1992), some consideration has been given to achieving the successful evacuation of offshore installations. In particular, this has included providing a range of evacuation methods for personnel on the installation. For fixed platforms in the North Sea, the most frequently employed alternative means of evacuation remains the lifeboat or Totally Enclosed Motor Propelled Survival Craft (TEMPSC) as it is known in the UK offshore industry.

These lifeboats come in a range of sizes and employ a variety of launching modes. However, within this project, emphasis has been placed on those vessels capable of holding around 50 persons and launched via davits (as opposed to freefall), this type representing the most typical craft currently employed on fixed platforms in the UK sector of the North Sea.

In various studies, risk analyses have been performed to consider the probability of successful launching of TEMPSC and escape from the installation, for a range of environmental conditions. It became clear that for severe environmental conditions, TEMPSC launched on the windward side of the installation, in particular, could impact the side of the structure during descent and be driven back into the structure by the action of waves and currents. Furthermore, there is the possibility of the craft becoming damaged or submerged due to wave action or during tow by a rescue vessel. In all such cases it is important that the structural integrity of the TEMPSC is maintained.

The purpose of this project is to review the design, choice of materials, fabrication and construction of a typical 50-man davit-launched TEMPSC, so that the capability and factors of safety can be determined for a number of accident scenarios. Phase 1 of the project (Ref. 1) comprised collation and review of background data and the results of this phase were presented in a separate report. Phase 2 of the project (Ref. 2) concerns the identification of design events for which the TEMPSC may suffer structural failure and the calculation of the strength at failure for each such event. Phase 3 of the project considers event levels and safety margins associated with the accident scenarios and thus quantifies the likelihood of failure for each event in the UK sector of the North Sea. . This document reports the results of phase 3 of the project.

5. Objectives and Scope of Work

Project Objectives:

The project objectives as stated in the Agreement between the UK Health and Safety Executive (HSE) and PAFA Consulting Engineers are as follows:

- ❑ To consider input data capture and review a range of 50 man (typical size) TEMPSC configurations from drawings, specifications and other literature.
- ❑ To ascertain TEMPSC construction material properties, fabrication procedures and failure assessment methodologies.
- ❑ To consider design events and failure strength.
- ❑ To identify relevant design events, such as:
 - boat clash with jacket brace,
 - dropping into still water or a representative wave from a prescribed height,
 - davit hanging overload,
 - hydrostatic immersion in the sea (upright or overturned),
 - stand-by vessel towing loads prior to recovery.
- ❑ To calculate failure capacities for each design event utilising existing or new analytical techniques.
- ❑ To consider event levels and safety margins.
- ❑ To determine appropriate performance levels for each event.
- ❑ To calculate a safety factor and margin against failure for each event.
- ❑ To produce a project report for each of the three project phases:
 - TEMPSC Structural Design Basis Determination
 - Part 1 - Input Data Capture and Review
 - Part 2 - Design Events and Failure Strength
 - Part 3 - Event Levels and Safety Margins

The range of Totally Enclosed Motor Propelled Survival Craft is limited to those currently stationed on fixed platforms located in the North Sea.

While this specification includes both davit-launched TEMPSC employing vertical winch systems and freefall launched TEMPSC employing an inclined ramp, the emphasis of the project, design specifications, launch events and safety margins relate to conventionally davit-launched TEMPSC. Furthermore, it is assumed that the TEMPSC is self-powered and piloted by a coxwain following release, rather than using a system that automatically pulls the craft clear of the structure.

Scope of Phase 3 – Event Levels and Safety Margins

The objective of the third phase of work in this project is to consider the likelihood of the TEMPSC failing in a structural manner during each specified design event. A number of design events were identified in phase 2. For each event, the average ultimate strength capacity of the TEMPSC was also determined.

In this phase of the project, these average ultimate strength capacities are compared with appropriate design loads so that the margin of safety may be estimated.

It was also agreed that a deterministic rather than probabilistic assessment should be made between the design loads and average ultimate strengths of the TEMPSC.

6. Analyses of TEMPSC Accident Scenarios

Introduction

In phase 2 of this project (Ref. 2), it was agreed in discussions with the HSE that six events related to the launch and escape conditions of TEMPSC should be considered. Each event represents an accident scenario as follows:

- Impact jacket member due to wind and oscillatory actions;
- Dropped into water due to winch/hook failure or release;
- Davit overload;
- Immersion in water;
- Damage/submersion during towing;
- Collision with jacket due to wave/current action following release.

In the following sections of this report, each event is considered with regard to the likely design load, the calculated average ultimate strength and the margin of safety between these two levels. It should be noted, however, that 'typical' events are being considered for a generic 50-man TEMPSC and that the safety margins determined are therefore illustrative rather than detailed design calculations.

Collision Between TEMPSC and Platform During Descent:

General:

As the TEMPSC is lowered vertically from winches on two cables, wind forces will act on the TEMPSC leading to oscillatory motions.

In strong wind conditions these motions could be sufficiently large to cause the TEMPSC to collide with the platform. However, there are a number of factors that need to be considered in determining the likelihood and forces involved in such a collision (see Figure 1):

- Wind direction relative to platform orientation.
- Wind speed and gustiness.
- Mass of TEMPSC and occupants.
- Area and shape of TEMPSC facing the wind.
- Distance between the platform and vertical descent of the TEMPSC.
- Total height of the descent.
- Air resistance and friction in the winch cable system.

- In addition, when considering the likelihood of such a collision in a given period, consideration should be given to:
- The annual number of TEMPSC launches.
- Rate of TEMPSC descent.

Assumptions

In this study, the following assumptions have been made regarding these parameters.

- It is assumed that davit-launched TEMPSC are located on all sides of the platform, and for an emergency evacuation all TEMPSC are launched.
- All wind is assumed perpendicular towards the windward face of the platform.
- The wind speed is based on a 50-year 3-second gust 10 m above SWL of 53 m/s (consistent with a 50-year 1-hour mean wind of 38 m/s, typical of the Northern North Sea - Ref. 3). The 3-second gust would appear to be appropriate for this size of structure as recommended in Ref. 3.
- For any wind speed, it is assumed that 72% of this wind is 'steady' while 28% is variable gust wind. These values are based on the 53 m/s 3-second gust and the 38 m/s 1-hour steady wind as recommended in Ref. 3. The steady component gives a fixed offset while the gust component is used to determine a secondary oscillatory effect.
- The relationship between wind speed and return period is based on the relationship (Ref. 3) where V can be based on any time interval, e.g. 1-hour mean, 3-second gust, etc:

$$VN = 0.71 (1 + 0.106 \ln N) V50$$

where V_N = Wind speed for a return period of N years

V_{50} = Wind speed for the return period of 50 years 10 m above SWL
(= 53 m/s)

N = Specified return period

- The variation of wind speed with height above SWL is based on (Ref. 4):

$$V_H = V_R \cdot (H/H_R)^n$$

where V_H = Wind speed at the specified height

V_R = Wind speed at the reference height (= 10 m)

H = Specified height above SWL

H_R = Reference height = 10 m

n = Power law exponent

= 0.077 for 3-second gust

= 0.150 for 1-hour mean wind

- The TEMPSC considered has a length of 8 m and side-on area of approximately $A = 15 \text{ m}^2$. A shape coefficient of $C_S = 1.0$ is assumed.
- The wind force is calculated by (Ref. 4):

$$F = 0.613.A.C_S.V^2 \quad (\text{in Newtons})$$
 where
 - A = Face area (m^2)
 - C_S = Shape coefficient
 - V = Wind speed (m/s)
- The TEMPSC has a fully laden weight of 7,600 kg and an unladen weight of 3,850 kg.
- The TEMPSC is stationed 30 m above SWL.
- Damping and friction effects are ignored.
- The TEMPSC motions are based on the behaviour of a simple pendulum, with the approximation $\sin x = x$ (in radians) assumed. The estimated TEMPSC motions and natural periods were checked by using hand calculations from first-principals. These calculations predicted a maximum oscillatory displacement at full winch extension around 50% of the steady wind displacement. These numbers were borne out in the spreadsheet calculations of motion as described below.

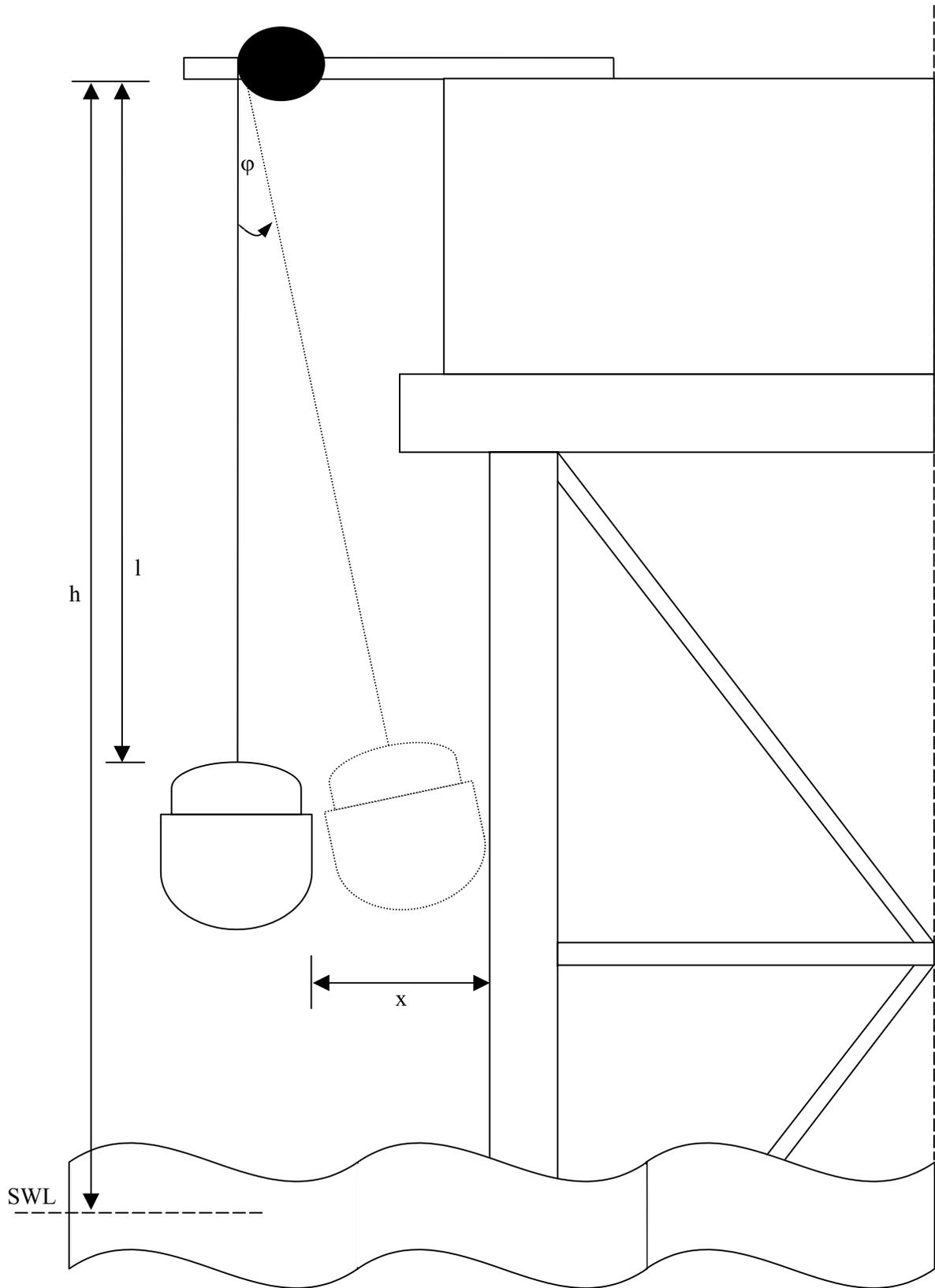


Figure 1
Model of the TEMPSC Colliding with a Platform Leg

Likelihood of Wind-Induced Collision with Platform Leg

For a specified return period and descent range, the wind speed is determined in terms of a steady wind component and a gust component. The offset of the TEMPSC due to the steady wind is calculated. A 3-second gust is superimposed on this wind (taking 0.75 seconds to build-up from and 0.75 seconds to decrease back-to the steady wind). The maximum displacements and velocities are determined during this process. In the analyses performed, the descent has been divided into six segments, each covering a range of 5 m.

The calculations have been performed for the two extreme TEMPSC weights:

- Fully-laden 50-man TEMPSC (7600 kg).
- Unladen 50-man TEMPSC (3850 kg).

The results of this analysis are given in Table 1. It can be seen that fully-laden, the TEMPSC can move a horizontal distance of up to 5.0 m towards the platform, while unladen this distance can be up to 9.9 m. However, it should be remembered that at the maximum displacement, the velocity of the TEMPSC will be zero.

An illustrative plot of the velocity (v) against distance is shown on Figure 2, for the fully-laden TEMPSC 2.5 m above SWL. In this case, the displacement due to the steady wind is 3.3 m ($v = 0.0$ m/s). As the gust is added on to the steady state wind, the TEMPSC accelerates to a point 4.2 m from the vertical where the maximum velocity of 0.57 m/s is achieved. The TEMPSC then decelerates to 5.0 m before swinging back past the vertical, in this case, at velocities of up to 1.0 m/s. The total curve represents 10 seconds – 0.75 seconds from zero to maximum gust, 3 seconds at maximum gust, 0.75 seconds returning to zero gust, and 5.5 seconds at zero gust.

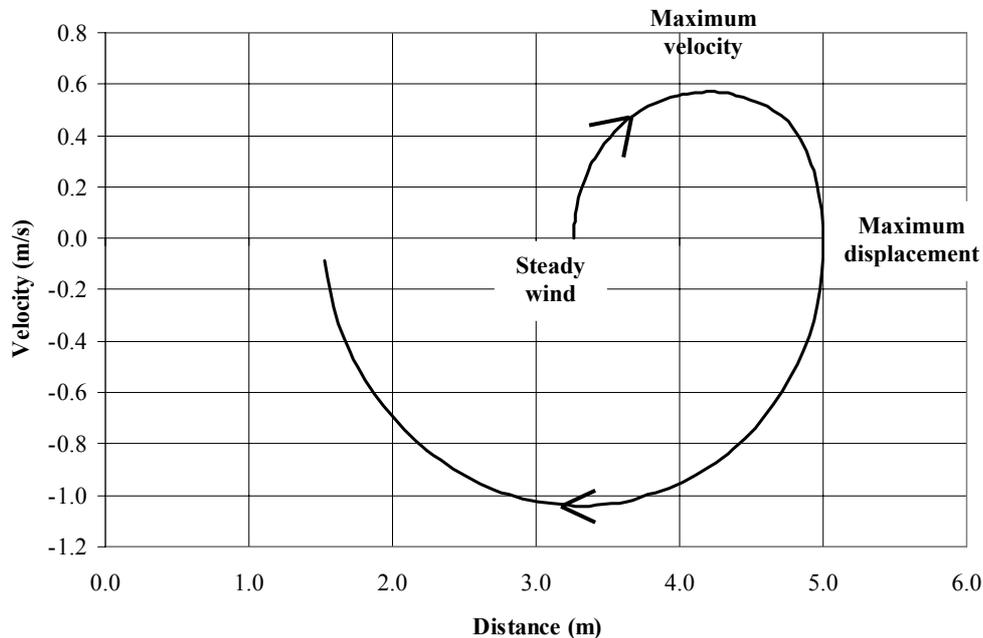


Figure 2

Plot of velocity against horizontal distance for a fully laden 50-man TEMPSC, Suspended 27.5 m and subjected to a 31 m/s steady wind + 16.8 m/s 3-sec gust

Table 1
Maximum displacement and velocity associated with 50-year wind

Height above SWL m	Steady wind speed m/s	3-sec gust speed m/s	Total wind speed m/s	7600 kg TEMPSC		3850 kg TEMPSC	
				Max. disp. m	Max. vel. m/s	Max disp. m	Max. vel. m/s
27.5	44.4	13.1	57.5	0.71	0.10	1.40	0.19
22.5	43.1	13.6	56.7	2.05	0.19	4.05	0.37
17.5	41.5	14.1	55.6	3.26	0.27	6.44	0.52
12.5	39.5	14.7	54.2	4.27	0.34	8.44	0.68
7.5	36.6	15.5	52.1	4.97	0.44	9.81	0.86
2.5	31.0	16.8	47.8	5.00	0.57	9.87	1.12

From phase 2 (Ref. 2) it was noted that the maximum energy that could be absorbed prior to structural collapse was 31.6 Nm per mm length of impact. From phase 2, failure of the hull was defined as flexural strains exceeding 2% (Ref. 2). By calculation, a 2% larger dented length (l_c) coincides with an original contact length $l = 337$ mm, see Figure 3. In this case, the maximum indentation is 29 mm.

When colliding with a 1.0 m diameter leg, the contact length prior to ultimate failure is taken to be 337 mm. Therefore, the maximum energy $\approx 10,500$ Nm.

For a fully laden TEMPSC $KE = 10,500 = \frac{1}{2} 7600 v^2$ i.e. $v_{max} = 1.66$ m/s

For an unladen TEMPSC $KE = 10,500 = \frac{1}{2} 3850 v^2$ i.e. $v_{max} = 2.33$ m/s

From Table 1, it can be seen that the TEMPSC should not fail structurally if it collides with a 1.0 m diameter leg at its maximum velocity due to wind forces. However, if the contact length were smaller, due to impact with a smaller diameter member, then ultimate failure could occur. For example, a near empty TEMPSC = 4000 kg would attain a maximum velocity around 1.1 m/s which would be sufficient to fail the TEMPSC over a contact length less than 75 mm, i.e. a member with diameter less than 450 mm.

NPD (Ref. 5) quote an annual probability of emergency evacuation from a UK fixed platform of 0.3%, based on historical data up to 1990. Based on 100 manned fixed platforms in the UK sector of the North Sea this implies $100 \times 0.3\% = 0.3$ platform emergency evacuations per annum in UK waters, or 15 emergency evacuations in 50 years (this assumes 1 windward TEMPSC per launch).

Therefore, both the probability of launching the TEMPSC in a high gust condition windward of the platform is small and the probability of the TEMPSC failing due to side impact with the platform prior to disconnecting from the winch in these conditions is small. For collision with a 1.0 m diameter leg, the safety factor on ultimate strength is in excess of four. However, this will reduce for small diameter legs to around 1.0 for a 250-450 mm leg depending upon the mass of the TEMPSC and occupants.

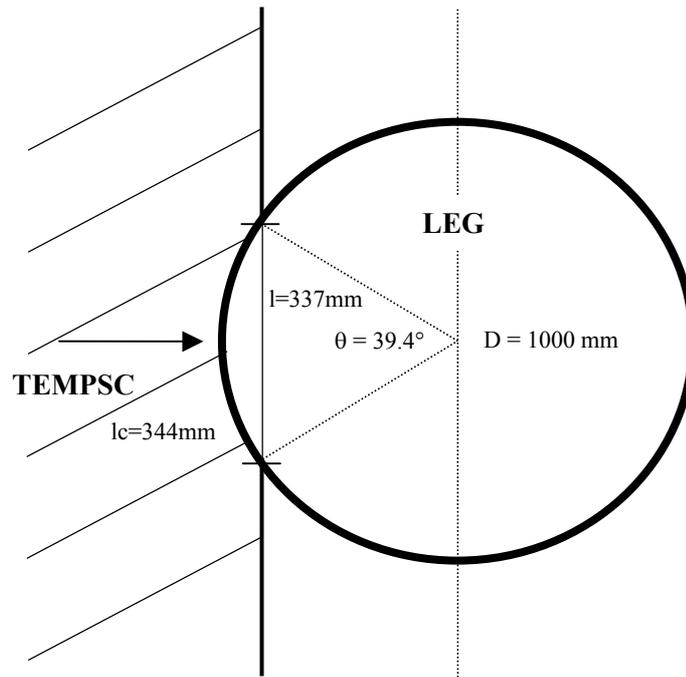


Figure 3
Maximum indentation of TEMPSC with strains less than 2% for collision
with a 1.0m leg

TEMPSC Dropping into the Sea During Descent

General

Some early accidents involving TEMPSC, in particular the Alexander Kielland incident (Ref. 5), became exaggerated as the TEMPSC could not be released unless there was slack in the wires – the off-load system. This was seen as a particular problem in heavy seas where the TEMPSC would be impacted by wave action.

In 1991, this led to the requirement that the release mechanism should be specified by an on-load system, allowing release at any stage in the descent provided sufficient safeguards were met. One consequence of this change has been the increased complexity of the hook design to prevent accidental release. This, in itself, led to concerns that the two hooks may not release simultaneously, or worse that the TEMPSC could remain attached to one hook and be unable to escape the platform.

Despite the safety features, a number of accidents have occurred with the TEMPSC falling by up to 30 m. However, these have been less public as, to date, they have been associated with isolated accidents and individual fatalities occurring during maintenance and offshore trials.

Assumptions

- The TEMPSC has a fully laden weight of 7,600 kg and an unladen weight of 3,850 kg.
- The TEMPSC is stationed 30 m above SWL.
- The release mechanism is on-load, so that it is feasible to release the TEMPSC from any height provided that the safety systems are over-ridden.

Likelihood of TEMPSC Dropping into the Sea

Estimates of the likelihood of the TEMPSC dropping from its hooks into the sea must be rather arbitrary. While some data exist on the hook release mechanism reliability and the lowering wires length and strength, the most likely cause of a premature release will be human error.

Probabilistic data from a study by PenTech for EM&I (Ref. 6, reviewed in Ref. 1) gave the total probability of the TEMPSC 'failing' during descent/release phase as 4.4%, see Table 2. The craft concerned was a 50-man Whittaker capsule suspended from one hook. However, the actual probability of the TEMPSC dropping is considered to be less than this value. For example, if the cable becomes jammed at 30m above the sea level then the chance of the coxwain opting to release the TEMPSC is very small and would only occur if all the occupant's lives were under immediate threat. However, for a case near the surface of the water, or in conditions with significant wave action, the coxwain is more likely than not to release the hooks and allow the craft to fall the few metres onto the surface of the sea.

It should also be noted in Table 2 that the proportions of each event occurring may vary in different environmental conditions. Consequently, four environmental conditions were defined with a frequency weighting factor, e.g. moderate conditions are defined to occur 61% of the time. These environmental weighting factors are based on wind data, which is more onerous than waves data. For example, a moderate wind speed of 7 - 16 knots is more common than a moderate wave height of say 5 - 10 m averaged across the North Sea. Since the likelihood of failure is more related to wave conditions than wind strength, the EM&I analysis may be weighted too much towards severe environmental conditions.

In Tables 2 and 3, probabilities have been adjusted to decrease the effect of severe environment but increase the human error, which are considered to be more significant. These probabilities, based on judgement, are expressed in terms of height above the sea surface (SWL) in 5m intervals and give a total probability of the TEMPSC falling as 3%.

From phase 2 (Ref. 2) it was noted that the maximum energy that could be absorbed prior to structural collapse was 280 Nm per mm length of impact. If the contact length is taken to be 'near-instantaneous' with half the length of the vessel, the total energy will be = 108.2 Nm per mm length x 4000mm = 432.8 kNm. Clearly, if the TEMPSC were to fall onto the crest of a passing wave, the contact length would be smaller, hogging moments would increase the loading and consequently the TEMPSC capacity would be reduced.

For a static wave, the maximum drop height would be:

$$\text{For a fully laden TEMPSC } PE = 432,800 = 7600 \cdot (9.81) \cdot h \quad \text{i.e. } h_{\max} = 5.80 \text{ m}$$

$$\text{For an unladen TEMPSC } PE = 432,800 = 3850 \cdot (9.81) \cdot h \quad \text{i.e. } h_{\max} = 11.5 \text{ m}$$

However, if the wave were taken to be 10 m in height and 3.4 seconds period, then the maximum vertical velocity in the wave would be an additional 2.92 m/s. Assuming the worst case and adding this component, the maximum drop height onto a dynamic 10 m wave would be:

$$\text{For a fully laden TEMPSC } h_{\max} = 3.1 \text{ m}$$

$$\text{For an unladen TEMPSC } h_{\max} = 7.4 \text{ m}$$

Therefore, it would be reasonable to assume that the TEMPSC would fail structurally if fully-laden and dropped from a height in excess of 5 m, or empty and dropped from 10 m or more.

Table 2
Failure probabilities for events relating to a TEMPSC being dropped
into the sea (Ref. 6)

WEATHER CONDITIONS	FAILURE PROBABILITIES			
	Calm	Mod- erate	Gale	Storm
ENVIRONMENTAL WEIGHTING FACTOR	0.237	0.610	0.148	0.005
STEP 7 CRAFT DESCENT BEGINS				
7.3 Brake lever or cable jammed by obstruction	0.0020	0.0020	0.0020	0.0020
7.4 Falls drum obstructed	0.0004	0.0004	0.0004	0.0004
	0.0024	0.0024	0.0024	0.0024
STEP 8 CRAFT DESCENT TO NEAR SEA LEVEL				
8.1 Brake/launch mechanism stuck on by falling debris	0.0004	0.0004	0.0004	0.0004
8.3 Release hook is inadvertently opened	0.0030	0.0030	0.0150	0.0150
8.5 Winch or brake mechanism seizes	0.0020	0.0020	0.0020	0.0020
8.6 Winch mechanism fails to control descent	0.0004	0.0004	0.0004	0.0004
8.8 Falls wire, splices, shackles or sheaves break	0.0020	0.0020	0.0020	0.0020
	0.0078	0.0078	0.0198	0.0198
STEP 9 DESCENT COMPETED				
9.2 Fall wire not long enough	0.0020	0.0020	0.0020	0.0020
STEP 10 RELEASE GEAR ACTIVATED				
10.1 Failure of ratchet, lock, etc.	0.0004	0.0150	0.1400	0.1400
Total probability of failure per environment	0.0126	0.0270	0.1607	0.1607
Total probability of failure (EM&I)	0.0440	4.4%		
Adjusted Environmental weighting factors	0.610	0.300	0.085	0.005
Total probability of failure (PAFA)	0.0302	3.0%		

Table 3
Probabilities of TEMPSC dropping from various heights

Drop Distance (m)	Drop Probability (%)
25 - 30	0.05 %
20 - 25	0.01 %
15 - 20	0.01 %
10 - 15	0.01 %
5 - 10	0.42 %
0 - 5	2.50 %
TOTAL	3.00%

From NPD (Ref. 5), 0.3 platform emergency evacuations per annum in UK waters are estimated. For all conditions, the probability of falling more than 5m fully-laden (emergency conditions) is estimated to be around 0.5% per launch, see Table 3. It may also be estimated that, on average, four TEMPSC will be launched per evacuation. Therefore, in 50 years it is anticipated $50 \times 0.3 \text{ emergencies} \times 4 \text{ TEMPSC launched} \times 0.55\% \text{ fall over 5m} = 33\%$ probability of one TEMPSC structural failure in 50 years.

In addition, there are also a number of trials both with and without a full complement of personnel. It is assumed that each platform launches one TEMPSC each year = 100 TEMPSC launches per year $\times 50 \text{ years} \times 0.3\% \text{ fall over 5 m}$ (lesser probability in calm – non-emergency conditions) = expectation of 15 structural failures in 50 years during trial launches. This figure is borne out by a number of falling TEMPSC reported to have led to death/injury in non-emergency conditions (Ref. 5).

TEMPSC and Occupants Overloading Davits

General

Unlike other seagoing craft, TEMPSC spend the majority of their life suspended in the davits, out of the water. In this condition, the loading is primarily the deadweight of the unladen TEMPSC, with a small additional contribution from wind load. During evacuation, personnel will board the TEMPSC prior to its launch from two davits.

Assumptions

- The TEMPSC has a fully laden weight of 7,600 kg (including allowances for equipment) and an unladen weight of 3,850 kg.
- The average weight of each person is 75 kg.
- There has been no significant degradation in strength over time.
- The load is assumed uniformly distributed over the length of vessel, between connections.
- Davit spacing assumed to be 7000 mm

Likelihood of TEMPSC Overloading Davits

SOLAS (Ref. 7, reviewed in Ref. 1) requires:

- The TEMPSC to be loaded up to twice its fully laden weight for a period of 18 hours with no residual deformations.
 - At 25% overweight the deflections should not exceed $1/400^{\text{th}}$ of the TEMPSC length.
 - At 100% overweight the deflections should be proportional to those at 25% overweight.
- The fixed structural connections of the release mechanism (tested separately) shall be shown to withstand loads six times the weight of the boat evenly distributed between supports [it is assumed that this weight is the fully-laden weight although this is unclear].

Taking the fully laden weight = 7,600 kg.
 25% overweight = 1.25 x 7600 kg = 9,500 kg
 100% overweight = 2.00 x 7600 kg = 15,200 kg

Maximum deflection at 25% overweight = $5qL^4/384EI$
 = $5(9500.9.81/7000).(7000)^4/[(384).(14000).(2.92E10)]$
 = 1.02 mm
 = 1/6862th of L < 1/400th L

Stress at 25% overweight = M/Z (canopy)
 = $[(9500.9.81/7000).(7000)^2/8]/[2.01E7]$
 = 4.06 N/mm²

Stress at 100% overweight = M/Z (canopy)
 = $[(15600.9.81/7000).(7000)^2/8]/[2.01E7]$
 = 6.66 N/mm²

From Ref. 2 it is clear that these stresses are well below the initial damage stress of around 112 N/mm².

In an emergency escape condition, the loads on the TEMPSC could differ from those specified in these tests by the following:

- The unladen weight of the craft (3850 kg) could be increased by some additional equipment being installed – a maximum increase of 20% = 770 kg would appear conservative.
- Rainwater could enter the TEMPSC during embarkation. Since the access is relatively small and the TEMPSC is some 30 m above SWL this is unlikely to be significant. However, in wet conditions the personnel are likely to bring water on-board via clothing, etc. A conservative estimate would be 1025 kg/m³ x (0.2 m x 6 m x 1.5 m) = 1845 kg.
- The average weight of each of the 50-personnel inside the TEMPSC could exceed 75 kg. However, since the TEMPSC has a very confined interior space it is difficult to imagine that the average weight could exceed around 100 kg before the full complement of 50 persons could not be achieved. Therefore the maximum personnel load is estimated to be 50 x 100 kg = 5000 kg.
- In addition to personnel inside the TEMPSC, in an emergency, some people may be holding onto the outside of the TEMPSC during launch. Possibly, a further 20 persons could be outside the TEMPSC = 20 x 100 kg = 2000 kg.
- There could be a wind load on the TEMPSC. If we take the 50 year 1-hour wind speed of 38 m/s applied over a surface area of 15 m², Ref. 4 suggests a force of $0.613(15)(1)(38)^2 = 13250$ N. Taking the vertical component of this force as 25% $F_{TOTAL} = 3313$ N.

Applying all of these figures (i.e. assuming a downward wind force) would yield a total weight of $W = 3850 \text{ kg} + 770 \text{ kg} + 1845 \text{ kg} + (50 \times 100 \text{ kg}) + (20 \times 100 \text{ kg}) + (3313 \text{ N}/9.81 \text{ m/s}^2) = 13800$ kg (i.e. 1.8 times the fully-laden weight).

From the above stress estimates, it appears that the davits themselves will fail before the hull. The davits must be proven at six times the (fully-laden) TEMPSC weight evenly distributed between davits, i.e. $7600 \text{ kg} \times 6 \div 2 = 22800$ kg. It would be anticipated that the mean strength would be a further 50% above this capacity = 34,200 kg. Therefore, the davits can probably withstand around nine times the fully-laden TEMPSC load.

Since the TEMPSC and davits have been proven at factors of two and six times the fully-laden weight, no failure can be envisaged provided all fastenings are correctly maintained and no significant loss of structural strength has occurred over time.

TEMPSC Complete Immersion in Sea

General

It is a concern that, in rough seas with breaking waves, the TEMPSC could become submerged and suffer structural damage. It is part of the SOLAS requirements (Ref. 7) that the TEMPSC be buoyant and self-righting, however, no requirement is made on its ability to withstand hydrostatic pressure to a particular depth.

Assumptions

- The TEMPSC is subjected to a uniform pressure, i.e. wave slamming effects have not been considered.
- The canopy is the weakest structural element that can fail.
- The canopy is considered to be semicircular.

Likelihood of the TEMPSC Failing Following Complete Immersion

In Phase 2 (Ref. 2) calculations were performed to show that the TEMPSC could withstand a hydrostatic pressure of 0.0101 N/mm per m, with the GRP material tensile hoop stress failing at 0.3286 N/mm. Thus a maximum depth of 32.7 m was estimated before the canopy fails.

The TEMPSC could be submerged by the following events:

- Rapid entry into the sea following release from the winch mechanism.
- Submergence by a breaking wave in shallow water depths.
- Towing through a wave front.

The TEMPSC is a buoyant vessel with a buoyant volume $\approx 8 \text{ m} \times 2 \text{ m} \times 2 \text{ m} = 32 \text{ m}^3$. None of the above events could submerge the TEMPSC by 33 m, sufficient to buckle the canopy.

It appears clear that this depth is well beyond the likely submergence of the TEMPSC, even noting the possible optimistic modelling of the canopy shape as a circular section. The maximum depth that could be envisaged for any part of the TEMPSC would be around 5 m.

Damage to TEMPSC During Towing

General

In conditions where the TEMPSC is being towed through oncoming waves there will be wave forces on the bow of the TEMPSC. It is considered that these forces may be larger than for the equivalent conditions where the TEMPSC is under its own motion, since the towed TEMPSC will, to some degree, resist the natural tendency to ride the waves. In this condition, damage could occur to the hull, but more likely would be failure of the towing connection

Assumptions

- The TEMPSC is fully laden with a weight of 7,600 kg.
- The maximum 50 year wave particle velocity is estimated to be = 5.5 m/s. This represents a wave of around $H_s = 15$ m significant height and $T_z = 13.15$ secs period ($v = (\pi 1.84 H_s) / (1.2 T_z) = 5.5$ m/s)
- The maximum towing speed is taken to be 2.5 m/s.
- The towing vessel is very large relative to the TEMPSC.
- The front of the TEMPSC has a section area taken to be = 5 m^2 ($A = \pi(2.5)^2/4 = 4.9 \text{ m}^2$).
- The drag coefficient of the front of the TEMPSC is taken to be 0.75.
- The towing rope and connections are sufficiently strong to resist the towing forces.
- The towing rope is assumed inelastic, thus all energy is taken by the TEMPSC.

Likelihood of the TEMPSC Becoming Damaged During Towing

For the above assumptions, the force on the TEMPSC is calculated by:

$$\begin{aligned} \text{Force} &= \frac{1}{2} \rho v^2 A C_D \\ &= 0.5 (1025)(5.5+2.5)^2(5)(0.75) \text{ N} \\ &= 123000 \text{ N} \end{aligned}$$

From Phase 2 (Ref. 2) it was calculated that the TEMPSC could resist at towing force of 1700 N for each mm length in contact with the bow wave. Therefore, the required length of TEMPSC to resist the estimated towing force is:

$$\begin{aligned} \text{Length} &= 123000 \text{ N} / 1700 \text{ N per mm length} \\ &= 73 \text{ mm.} \end{aligned}$$

This is a short length compared to the width of the bow, which can be estimated to be around 1000 mm in length.

SOLAS (Ref. 7) requires that the towing connections are to be of sufficient strength to enable a full-laden TEMPSC to be launched and towed at a speed of 5 knots in calm water.

The calculation of the force on the bow of a TEMPSC moving at 5 knots through calm water is a simple calculation if the various resistance coefficients are known. The formula for resistance being:

$$R = \frac{1}{2} C \rho S v^2$$

where C is the resistance coefficient, with frictional, residual and wave-making components.

ρ is the water density = 1025 kg/m^3 in sea-water.

S is the wetted surface.

v is the speed of the vessel.

If C is taken to be = 5×10^{-3} (the upper end of its range $1-5 \times 10^{-3}$) and the wetted area is based on the TEMPSC being a half-cylinder then:

$R = \frac{1}{2} \cdot 5 \times 10^{-3} \cdot 1025 \text{ kg/m}^3 \cdot 36 \text{ m}^2 \cdot (2.5 \text{ m/s})^2 = 580 \text{ N}$, which is equivalent to a 60 kg weight hanging off the towing connection. It is anticipated that a design factor of six would be applied to

meet SOLAS requirements, along with an additional 50% design allowance. Therefore, it is estimated that the failure load on the towing connection would be around 5220 N.

In more severe seas, the TEMPSC velocity would be a combination of the wave and towing speeds. These cannot be simply combined. Vessels individually will try to ride the wave, but when attached by the tow-line will have some effect upon each other's motion. The combined wave and tow speed is estimated to be 6 m/s, giving a force of almost 3321N, i.e. 64% of the estimated connection strength.

The tow-line is designed to be less than 67% the capacity of the connections, therefore, any failure during tow is likely to be of the tow-line. Therefore, the safety margin for tow in a 50 year wave is around 1.0.

Collisions Between TEMPSC and Platform During Evacuation

General

Following release from the winch mechanism, the TEMPSC will be parallel to the platform and perpendicular to its recommended direction of escape. The TEMPSC must turn through 90°, which will result in its stern moving nearer to the platform (set-back). In addition, if the prevailing environmental conditions are towards the platform, the TEMPSC will approach the platform as it manoeuvres perpendicular to the platform (wash-back).

Several factors will effect the path of the TEMPSC as it attempts to clear the platform:

- ❑ The location at which the TEMPSC enters the sea. This will be a function of the strength and direction of the wind.
- ❑ The delay, if any, to engage the engine and accelerate to maximum speed.
- ❑ The maximum speed of the TEMPSC.
- ❑ The wave velocity and direction.
- ❑ The current velocity and direction.

The likelihood of the TEMPSC colliding with the platform is then a function of these variables along with the distance to the platform's legs and members.

Assumptions

- ❑ The TEMPSC is fully laden with a weight of 7,600 kg.
- ❑ From Section 3.2, the fully-laden TEMPSC will fail if it collides with a 1.0 m diameter member at a velocity in excess of 2.88 m/s.
- ❑ The current is taken to be 0.5 m/s.
- ❑ The TEMPSC maximum velocity is taken to be 6 knots (3.08 m/s).
- ❑ The TEMPSC maximum acceleration is taken to be 1 m/s².

- The TEMPSC can orientate by a maximum of 15° per second as it attempts to clear the platform. Therefore, it will take 6 seconds to orientate from parallel to perpendicular to the platform.

Likelihood of the TEMPSC Colliding with the Platform Following Release

The calculation of the TEMPSC path as it manoeuvres to escape the platform is calculated in a number of stages.

1.0 Wind-induced Displacement.

In a similar manner to Section 3.2, the horizontal displacement of the TEMPSC can be determined for a given wind velocity – assumed perpendicular towards the platform.

In this scenario, the wind speed is assumed constant based on a 50-year, 1-hour wind speed = 38 m/s 10 m above SWL, i.e. there is no gust - TEMPSC oscillation factor. The wind speed is then determined 2.5 m above SWL, based on a total descent distance of 30 m. From this value, the force on the TEMPSC is determined as per Section 3.2. Based on this calculation, a horizontal displacement is calculated.

2.0 Wave-induced Displacement

The wave velocity is determined as per Section 3.6. The significant wave height (Hs) is estimated for a given return period based on a Fisher-Tippet Type I distribution with slope and shape coefficients = 1.600 and 1.125 respectively (Ref. 8). From this value, wave steepness (s), wave period (Tz), associated wave period (Tass), number of zero-crossing waves (Nz) and the extreme wave height (H) can be deduced.

The wave particle velocity is determined by $v = \pi H / T_{ass} = 5.49$ m/s for a 50-year return period.

The current is assumed coincident to the wave direction and thus is simply added to the wave velocity.

3.0 Delayed release Displacement

For any specified time delay in engaging the engine, the displacement is simply calculated as the wave velocity multiplied by the length of the delay.

4.0 Vessel Displacement

Once the engine is engaged, the TEMPSC is considered to accelerate at 1 m/s² up to its maximum speed of 6 knots, i.e. it will take 3.1 seconds to reach maximum speed. An iterative process is employed to determine the speed and direction of the TEMPSC as it turns perpendicular to the platform. The calculated motions are adjusted by the velocity of the wave.

From Section 3.2.2, it was shown that colliding with a 1.0 m diameter leg,, the maximum energy $\approx 10,500$ Nm.

For a fully laden TEMPSC $KE = 10,500 = \frac{1}{2} 7600 v^2$ i.e. $v_{max} = 1.66$ m/s

For an unladen TEMPSC $KE = 10,500 = \frac{1}{2} 3850 v^2$ i.e. $v_{max} = 2.33$ m/s

It can be seen that for a 50-year wave, since the wave +current velocity of 5.99 m/s exceeds the maximum TEMPSC velocity = 3.08 m/s, the TEMPSC must collide with the platform, irrespective of other factors. If the TEMPSC can orientate perpendicular to the platform before the collision, then the collision velocity will be $5.99 - 3.08 = 2.91$ m/s, sufficient to fail the TEMPSC irrespective of weight.

Even at lower impact velocities, the damage at the stern of such a collision will probably result in the destruction of the propeller and rudder, leading to further impacts at higher impact velocities sufficient to fail the hull.

Back-calculating the return period to generate a wave + current velocity of less than 3.08 m/s suggests a wave with a return period of around 1 day (see Table 4). However, it should be noted that the wave exceedance curve is not designed for such high frequency events and hence its accuracy should be treated with caution. As a guide, Table 4 illustrates a range of extreme wave return periods along with their estimated significant wave heights and velocities.

In Figure 4, one example escape path is plotted to illustrate the motion of the TEMPSC.

Table 4
Estimated wave heights and velocities for a range of return periods

Return Period	Significant wave height (m)	Wave particle velocity + current (m/s)
50 years	15.00	5.99
1 year	10.60	5.14
1 day	3.86	2.94
12 hours	3.00	2.51
6 hours	2.01	1.98

In this example, the constant wind speed is 20 m/s into the platform. This leads to the TEMPSC entering the sea 0.9 m nearer the platform than the vertical descent. It is assumed that the engine has been engaged prior to entry into the sea and consequently the TEMPSC may immediately begin to manoeuvre. The wave + current velocity has been specified to be 2 m/s towards the platform.

In Figure 4, each bar represents the TEMPSC with the circles representing the bow, centre and stern of the TEMPSC along its centre-line. Each bar illustrates the location of the TEMPSC at 0.2 second intervals. It can be seen that the TEMPSC suffers both set-back and wash-back as it manoeuvres around to the perpendicular at which point it will have an exit velocity of $3.08 - 2.00 = 1.08$ m/s.

The maximum distance moved by the stern from the descent position is 7.5 m. In this example, if the TEMPSC were to impact a 1.0 m diameter vertical member at 6.0 m from the vertical descent position, then the impact velocity would be 2.95 m/s, i.e. sufficient to fail the TEMPSC, if fully laden.

It can be seen that there are a large number of variables in this analysis. However, it can be concluded that any TEMPSC launched a short distance away from the platform into a moderate sea, with wave motion towards the platform, is likely to collide with some jacket member(s) at velocities likely to cause damage to propulsion and steering equipment and to suffer significant structural damage.

From Ref. 5, discussed in Section 3.2.2, it is estimated that there will be 15 emergency launches of TEMPSC in 50 years in the UK Sector of the North Sea, where one TEMPSC will be launched on each side of the platform. The likelihood of a launch in moderate, gale or storm conditions are around 1 in 5, leading to an estimate of three structural failure events where the TEMPSC collides with the platform in a 50 year period.

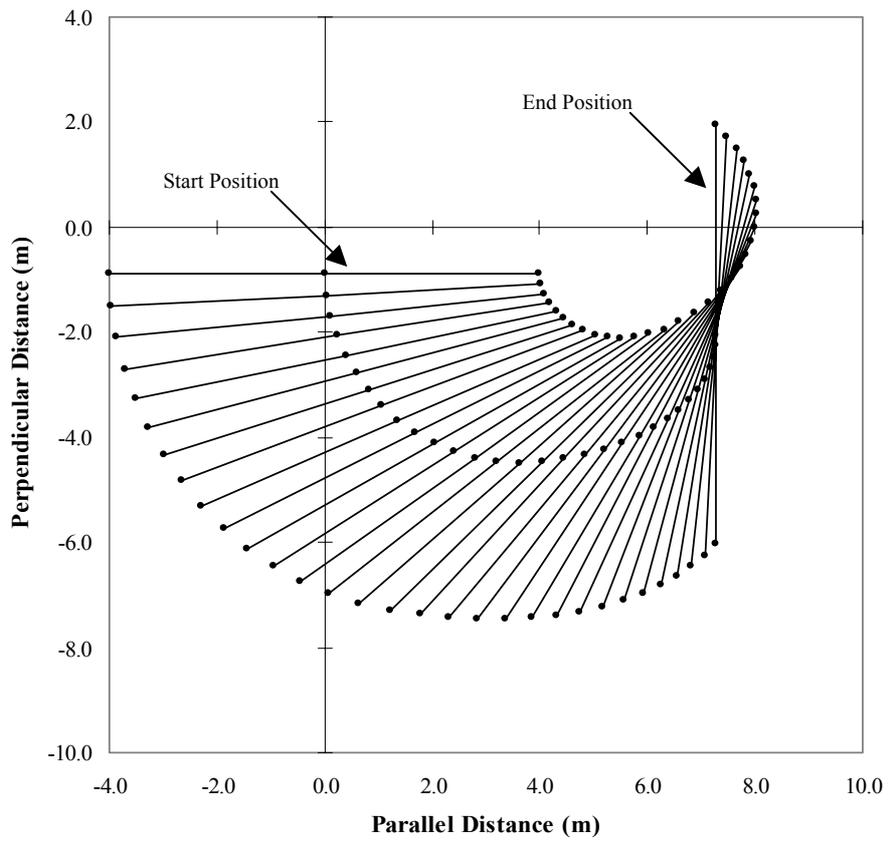


Figure 4
Example of a TEMPSC manoeuvring to escape from a platform
in moderate wind and wave conditions

7. Safety Margins

SOLAS (Ref. 7) requires:

Para. 6.1.1.6 Issue: Structural member factors of safety requirements

All structural members, blocks, links, fastenings, etc. are to be designed on a factor of safety of 4.5 based on the maximum working load and the ultimate strength of the material. For fall suspension chains, shackles and rigging, a minimum factor of safety of 6 shall apply.

In this project, the estimation of safety margins is rather arbitrary based on the generic 50-man TEMPSC selected and the scenarios assessed. For better estimates of safety levels, the lifeboat and offshore industries need to assess the assumptions about material properties and analytical models made in Phase 2, and the likelihood of TEMPSC launches and assumptions concerning the accident scenarios, considered in this Phase of the project. However, despite this need for industry feedback, some important observations can be made regarding safety levels:

- Based on the 50-year design wind and gust loads applied perpendicular to the TEMPSC, the TEMPSC will probably not fail. There is a safety margin between the design load and mean strength of 2 to 3. The likelihood of such high wind loads coinciding with a TEMPSC launch is very small.
- The TEMPSC will probably fail if it falls into the sea from a height over 5 m (fully laden) or over 10 m (empty). Therefore there is no safety margin between the design load and mean strength. However, the likelihood of such an event is small during emergency evacuations. Of greater concern are trial launches. An estimate of one trial launch per platform per year, in the UK sector of the North Sea, leads to an estimate of 15 failures in 50 years. These figures are supported by historic data primarily from Norwegian incidents (Ref. 5):
 - worldwide, 42 people died during evacuation of the Enchova when its lifeboat fell into sea;
 - in the North Sea, 3 people died in 1975 when a lifeboat fell into sea off Ekofisk 2/4;
 - during maintenance in the Norwegian North Sea, 2 people died in 1985 when a fast rescue craft fell into the sea off Borgsten Dolphin semi-submersible;
 - during maintenance in the Norwegian North Sea, 2 people died in 1994 when a davit launched lifeboat fell 30 m off the Condeep platform;
 - during drill in the Norwegian North Sea, many back injuries occurred in c.1980 when a davit launched lifeboat fell 10 m off the Sedco Phillips Service Rig.
- The estimated safety level of the TEMPSC supported in its davits, based on SOLAS requirements (Ref. 7), is 17, while for the davits themselves; a safety margin of 9 appears appropriate.
- For the TEMPSC to be submerged to 33 m at which failure is predicted would require an unrealistically large force to be applied to the TEMPSC. It is envisaged that a safety margin of around 6.5 is appropriate for this event.
- During design tow loads, structural failure of the bow appears unrealistic. However, the tow connector could fail at a factor of 9 times the towing force in calm water. While the 50 year wave loads do not appear sufficient to fail the connections, the tow-line itself may fail

in this condition. Consequently, a safety margin of around 1.0 is estimated for any failure during tow.

- Based on the 50-year design wave, the TEMPSC will probably collide with the platform and fail if this load is applied perpendicular to the TEMPSC. Therefore there is no safety margin between the design load and mean strength. The likelihood of the moderate wind and wave conditions required to cause failure suggest that 5 such accidents may occur in 50 years.

8. Observations

This project is concerned with structural strength for specified loads and the likelihood of structural failure of davit launched TEMPSC during the launch and evacuation from a fixed steel platform in the UK sector of the North Sea.

In Phase 1 of the project, it was shown that there is very little data in the public domain relating to structural behaviour of TEMPSC. A prototype of each new design of these craft is required to meet a number of structural and performance testing criteria. Provided that these tests are met, and each TEMPSC produced does not deviate from the prototype, there appears to be no further regulatory requirements on TEMPSC during their lifetime.

In Phase 2 of the project, estimates were made of the properties of the structural material used to construct TEMPSC and of the forces and energies required to fail this material under a range of loading conditions. Each of these loading conditions was specified to represent a potential failure condition during the evacuation and escape of personnel from fixed steel platforms.

In this phase of the project, the information derived in Phases 1 and 2 were combined with loading data to quantify the likelihood of structural failure of TEMPSC. Of the six design events, it is concluded that, based on the assumptions made in this project, there is little likelihood of the TEMPSC suffering structural failure when supported on its davits, due to wind loading during descent, or due to water pressure during submergence.

The results of the study indicate, however, that it is possible for the TEMPSC to suffer structural failure following collision with a structural member once in the water. This is particularly the case with davit launched TEMPSC which enter the sea parallel to the platform and have to manoeuvre around by 90° to escape the platform. It is shown that moderate environmental conditions can generate sufficient force to lead to failure of the TEMPSC. However, since a TEMPSC would be launched on the windward side of the platform into moderate seas only during emergency situations, it is estimated that the likelihood of such an event would be around once in 15 – 20 years.

Under tow in heavy seas, it is estimated that the tow-line between the towing vessel and the TEMPSC could fail. If the TEMPSC has no independent power then it could drift back into the platform or into another vessel or structure.

Overall, the most likely cause of structural failure is due to the TEMPSC falling into the sea. It is estimated that a fully laden TEMPSC will exhibit structural failure if dropped by more than 5m, while a near empty TEMPSC would need to fall by more than 10m to fail. While it is estimated that such an event may occur around once every 150 years during an emergency evacuation, it is felt that this likelihood may increase to once every 3 years during trial launches and maintenance, due to their greater frequency. These figures appear to be supported by data primarily from Norwegian waters, which show a number of deaths and injuries arising in these circumstances over the last 25 years.

It is recommended that:

- Due to the lack of industry verification of material data, in particular, a number of assumptions were necessary when carrying out the damage assessment. Therefore, the assumptions made in this report need to be independently reviewed and verified.
- Data relating to TEMPSC incidents worldwide and in the UK sector of the North Sea be collated and compared to the estimates made in this project.
- The impact forces and energies in the three more likely accident scenarios be related to forces and accelerations on the evacuees, so that personnel injuries can be quantified.
- A risk analysis be performed to generate improved data on the likelihood of such events occurring and the most cost-effective method of mitigation of such events.

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