

**RELIABILITY & RISK ASSESSMENT  
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**SAFETY INTEGRITY ASSESSMENT OF EASA PROPOSALS  
for  
MANDATORY EMERGENCY LOCATION TRANSMITTERS  
&  
FLOATATION EQUIPMENT**

**ROBINSON R22 & R44 HELICOPTERS**

Technis Report No T470

**CONTENTS**

Executive Summary & Recommendations  
1. Objectives & Risk Targets  
2. Assumptions  
3. Review of Scenarios  
3.1 Emergency Location Transmitter  
3.2 Floatation Equipment  
4. Failure Rate & Incident Data  
5. References  
APPENDIX 1 - Fault Tree Details  
APPENDIX 2 – Brief Analysis of forced landing terrain

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Issue 1.0  
22 July 2009

## EXECUTIVE SUMMARY & RECOMMENDATIONS

### OBJECTIVES

Following EASA proposals, to carry out a quantitative risk assessment in order to review the proposals to fit Emergency Location Transmitters and Floatation Equipment to Robinson R22 and R44 helicopters.

### TARGETS AND RESULTS

	<b>TARGET Maximum tolerable risk (pa)</b>	<b>PREDICTED Fatality rate (pa)</b>	<b>COST per Life Saved</b>
3.1a) Fatality following forced landing with no ELT	<b>10<sup>-4</sup></b>	<b>8.6 10<sup>-5</sup> which meets the target</b>	
3.1b) Fatality following forced landing with ELT fitted	<b>10<sup>-4</sup></b>	<b>1.1 10<sup>-5</sup> which meets the target</b>	<b>£7,000,000</b>
3.2a) Fatality following forced landing without Floatation Equipment	<b>10<sup>-4</sup></b>	<b>7.2 10<sup>-5</sup> which meets the target</b>	
3.2b) Fatality following forced landing with Floatation Equipment	<b>10<sup>-4</sup></b>	<b>1.5 10<sup>-5</sup> which meets the target</b>	<b>£15,000,000</b>

### RECOMMENDATIONS

Note that the scenarios (3.1a and 3.2a) meet the risk targets without the additional mitigation and that the Cost per Life Saved of the additional risk reduction (scenarios 3.1b and 3.2b) is disproportionate (section 1.4).

Fit ELTs as a voluntary option.

Continue to use the R22 offshore without floatation equipment but with life jackets. Fit floats to the R44 only as a voluntary option.

Whilst this study is based upon R22 and R44 incident data, and perceived operating scenarios, consider applying the findings to other machines.

Note that the probability of a forced landing, involving hostile terrain, is far greater for the R44 (due to the nature of its use). A more detailed study would address scenario 3.1 separately for the two machines.

### THOSE INVOLVED

This study was based on ref 5.6. It involved discussions with, and opinions from, Mr James Tuke of Thurston Helicopters, Headcorn. The author's credentials can be assessed from the Technis website ([www.technis.org.uk](http://www.technis.org.uk)).

## 1. OBJECTIVES & INTEGRITY REQUIREMENTS

### 1.1 OBJECTIVES

1.1.1 To respond to EASA consultation document NPA 2009-02b pages 41-46 & 197-205 (ref 5.6).

1.1.2 To carry out a quantitative risk assessment in order to review the proposals to fit Emergency Location Transmitters and Floats to Robinson R22 and R44 helicopters.

1.1.3 To establish safety-integrity (risk) targets.

1.1.4 To assess two scenarios (fatality following forced landing & fatality following ditching) against the targets.

1.1.5 To make recommendations.

### 1.2. RISK TARGETS

Reference 5.3 currently compares maximum tolerable risk targets for a range of industries. The current suggestions for maximum tolerable risk, which are an order of magnitude more onerous than the broad HSE discussion document (Ref 5.4) are, for individual risk:

FATALITIES (EMPLOYEE/VOLUNTARY)	- $10^{-4}$ pa
FATALITIES (PUBLIC/INVOLUNTARY)	- $10^{-5}$ pa
BROADLY ACCEPTABLE	- $10^{-6}$ pa

The scenarios involve private aviation and thus, the **individual maximum tolerable risk has been taken as  $10^{-4}$  pa**. Unlike the scenario argued in Ref 5.8, it is assumed that the scenarios addressed in this study represent a single risk at the time in question.

### 1.3 SCOPE OF THE ASSESSMENT

The equipment involved includes:

Portable Location Beacon (PLB) & battery

*Proposed* Emergency Location Transmitter (ELT) & sensor & battery

Mobile Telephone including battery

Floatation Equipment (system)

### 1.4 ALARP

The ALARP (as low as reasonably practicable) principle involves deciding if the cost and time of any proposed risk reduction is, or is not, grossly disproportionate to the safety benefit gained. The demonstration of ALARP is supported by calculating the Cost per Life Saved of the proposal. The process is described in Ref 5.2. Successive improvements are considered in this fashion until the cost becomes disproportionate. From ref 5.3, a cost per life saved criterion of £4,000,000 has been used together with a 10 year equipment life.

Cost per life saved =

(Proposed cost)/ (Risk reduction as a result of proposal x item life x number of lives at risk)

## **2. ASSUMPTIONS**

### **2.1 SPECIFIC**

2.1.1 The proof-test interval for unrevealed faults is pessimistically assumed to be one week for a mobile phone and six months for an ELT or PLB. The ELT sensor is assumed not to be effectively tested and therefore has a proof test interval equal to the equipment life.

2.1.2 An Engine Off Landing (EOL) outside the training environment will lead to fatality, or serious injury, one time in 5. The data in reference 5.7 suggests 20%.

#### **2.1.3 *VIS-À-VIS Ditching***

a) Life jackets will fail to be carried for flights exceeding the auto-rotation distance over water, on 75% of occasions.

b) The water/sea conditions render the flotation mitigation ineffective on 10% of occasions. When it is effective it assumed that fatalities will be avoided.

c) If all mitigation fails there will be a 90% chance of non-survival without a life jacket and a 20% chance of non-survival with a life jacket.

d) The cost of fitting floatation equipment is £15,000. Assuming £200pa maintenance this effectively raises the capital cost to £17,000.

#### **2.1.4 *Vis-a-Vis ELT Mitigation (forced landing in a hostile terrain)***

a) There is a 75% chance that a PLB (Personal Locator Beacon) will be carried.

b) There is a 90% chance that a Mobile telephone will be carried.

c) There is a 75% chance that the Mobile telephone will not be within range of a signal.

d) There is a 50% chance that the Mobile telephone user will be unable to accurately describe his/her position.

e) There is an 60% chance that the last Mayday or other radio communication is ineffective in directing rescue activities.

f) There is a 75% chance that dramatically delayed rescue leads to a fatality that would not otherwise occur.

g) There is a 10% chance that passenger(s) both survive the impact and are sufficiently injured to be in need of swift attention. Note that death and minor injury do not require the response addressed in this scenario

h) There is a 33% chance that, given survivor(s), one is able to communicate via the facilities available.

i) There is a 25% chance that the incident involves terrain appropriate to this study. Ref 5.7, Study T419 describes 27 landings (See App 2).

j) The cost of an ELT £1850 (ref 5.6) and it assumed that this would lead to a cost of £3,000 fitted. Assuming £200pa maintenance this effectively raises the capital cost to £5,000.

- k) The chance that the impact is sufficiently light for the ELT not to be activated is 10%.
- l) The ELT cannot be inhibited from the cockpit.

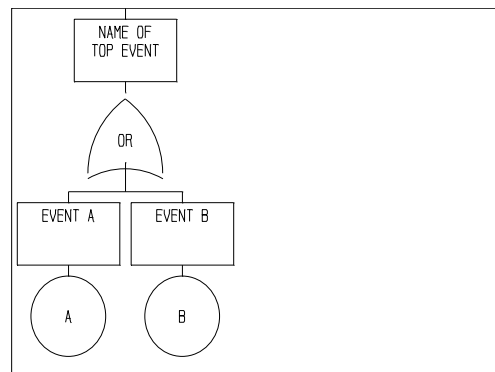
2.1.5. A pilot typically makes 195 sorties pa of approximately one hour duration (section 4).

## 2.2 GENERAL

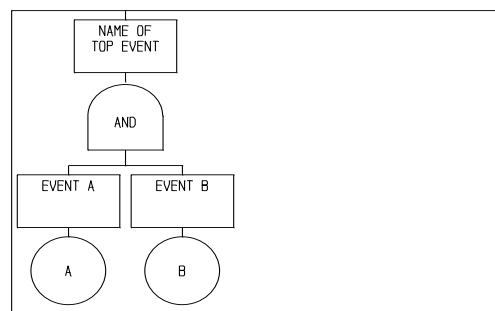
2.2.1 Reliability assessment is a statistical process for applying historical failure data to proposed designs and configurations. It therefore provides a credible target/estimate of the likely reliability of equipment assuming manufacturing, design and operating conditions identical to those under which the data was collected. It is a valuable design review technique for comparing alternative designs, establishing order of magnitude performance targets and evaluating the potential effects of design changes. The actual predicted values cannot, however, be guaranteed as forecasting the precise number of field failures which will actually occur, since this depends on many factors outside the control of a predictive exercise.

2.2.2 Failure rates (symbol  $\lambda$ ), for the purpose of this prediction, are assumed to be constant with time. Both early and wearout related failures would decrease the reliability but are assumed to be removed by burn in and preventive replacement respectively.

2.2.3 Each single component failure which causes system failure is described as a SERIES ELEMENT. This is represented, in fault tree notation, as an OR gate whereby any failure causes the event. The system failure rate contribution from this source is obtained from the sum of the individual failure rates.



2.2.4 Where coincident failures are needed to fail for the relevant system failure mode to occur then this is represented, in fault tree notation, as an AND gate where more than one failure is needed to cause the event.



### **3. REVIEW OF SCENARIOS**

#### **3.1 PROPOSED EMERGENCY LOCATION TRANSMITTER (ELT)**

In this scenario, a forced landing leads to fatality due to delayed rescue resulting from the failure of communications. The effect of carrying an ELT is tested. A 1 fatality scenario is assumed. The maximum individual tolerable risk target is **10<sup>-4</sup> fatalities pa**.

##### **3.1.1 Assessment of the Scenario**

The fault tree (Figure 3.1a) was constructed to model the scenario without the benefit of an ELT. It was analysed using the TECHNIS fault tree package TTREE (Ref 5.5). The details are shown in Appendix 1. The frequency of the top event is **8.6 10<sup>-5</sup> pa** which meets the target.

(Figure 3.1b) shows the modified fault tree which credits the mitigation offered by the ELT. The details are shown in Appendix 1. The frequency of the top event is **1.1 10<sup>-5</sup> pa** which meets the target.

##### **3.1.2 ALARP**

Assuming the cost of an ELT system is £5,000 and assuming a ten year life then the cost per life saved arising from the risk reduction is:

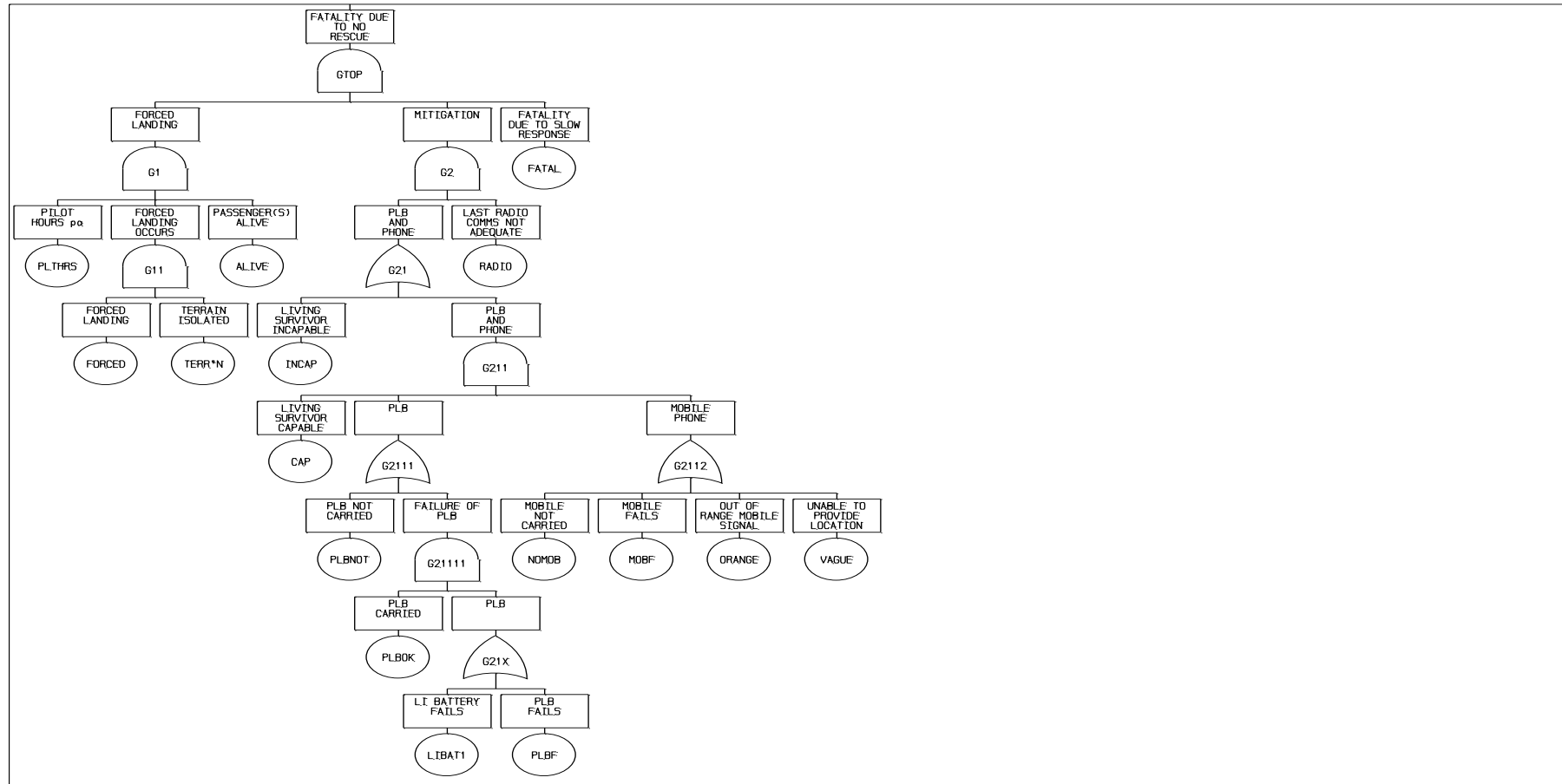
$$£5,000 / (8.6 \times 10^{-5} - 1.1 \times 10^{-5}) \times 1 \times 10 = \text{£7 Million pounds.}$$

Since this exceeds the criterion mooted in section 1.4, ALARP is claimed to be satisfied without the additional risk reduction.

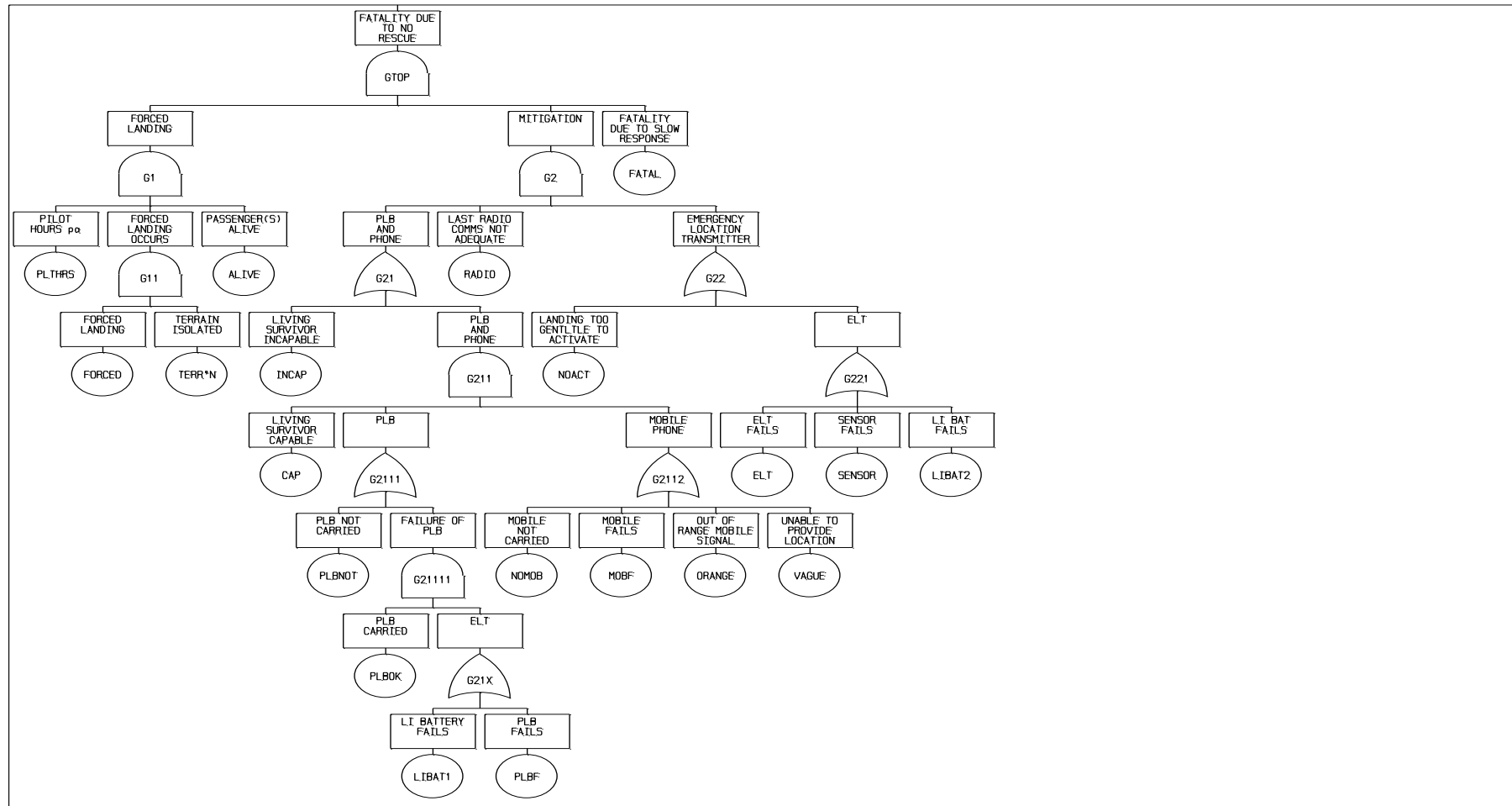
##### **3.1.3 Recommendation**

The fitting of emergency location transmitters shall be optional.

**FIGURE 3.1a- FAULT TREE - INVOLVING NO ELT**



**FIGURE 3.1b- FAULT TREE - INVOLVING AN ELT**



## 3.2 PROPOSED FLOATATION EQUIPMENT

In this scenario, a forced landing on water leads to fatality due to life jackets and/or floatation equipment being ineffective. A 2 fatality scenario is assumed. The maximum individual tolerable risk target is  $10^{-4}$  fatalities pa.

### 3.2.1 Assessment of the Scenario

The fault tree (Figure 3.2a) was constructed to model the scenario without the benefit of floatation equipment. It was analysed using the TECHNIS fault tree package TTREE (Ref 5.5). The details are shown in Appendix 1. The frequency of the top event is  $7.2 \times 10^{-5}$  pa which meets the target.

(Figure 3.2b) shows the modified fault tree which credits the mitigation offered by floatation equipment. The details are shown in Appendix 1. The frequency of the top event is  $1.5 \times 10^{-5}$  pa which also meets the target.

### 3.2.2 ALARP

Assuming the cost of a floatation system is £17,000 and assuming a ten year life then the cost per life saved arising from the risk reduction is:

$$£17,000 / (7.2 \times 10^{-5} - 1.5 \times 10^{-5}) \times 2 \times 10 = \text{£15 Million pounds.}$$

Since this exceeds the criterion mooted in section 1.4, ALARP is claimed to be satisfied without the additional risk reduction.

### 3.2.3 R22 v R44

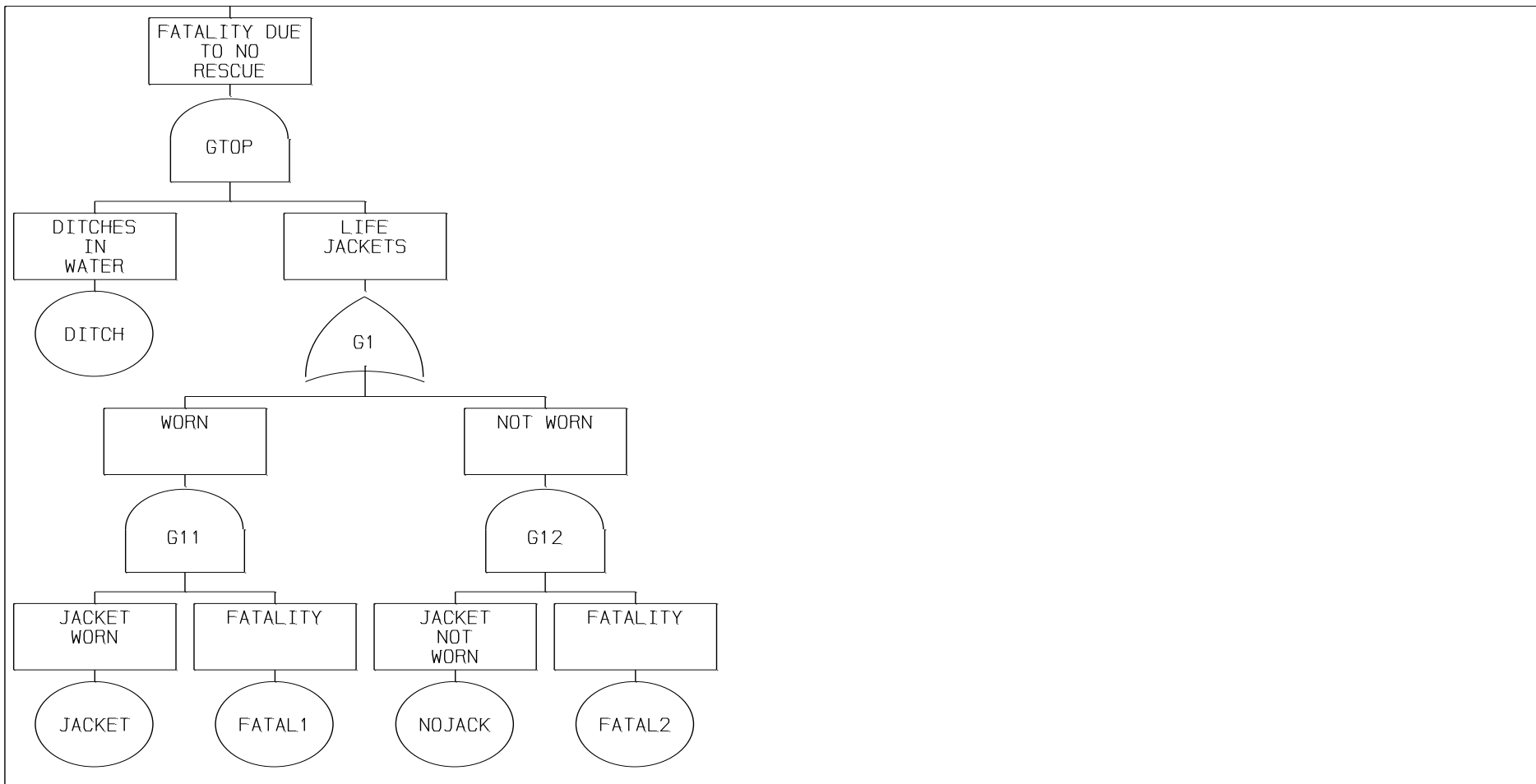
The case is argued for both R22 and R44 machines.

However floatation equipment cannot be fitted to the R22. Nevertheless, it meets the maximum tolerable risk criteria without that additional risk reduction and is shown to be ALARP by virtue of the Cost per Life Saved.

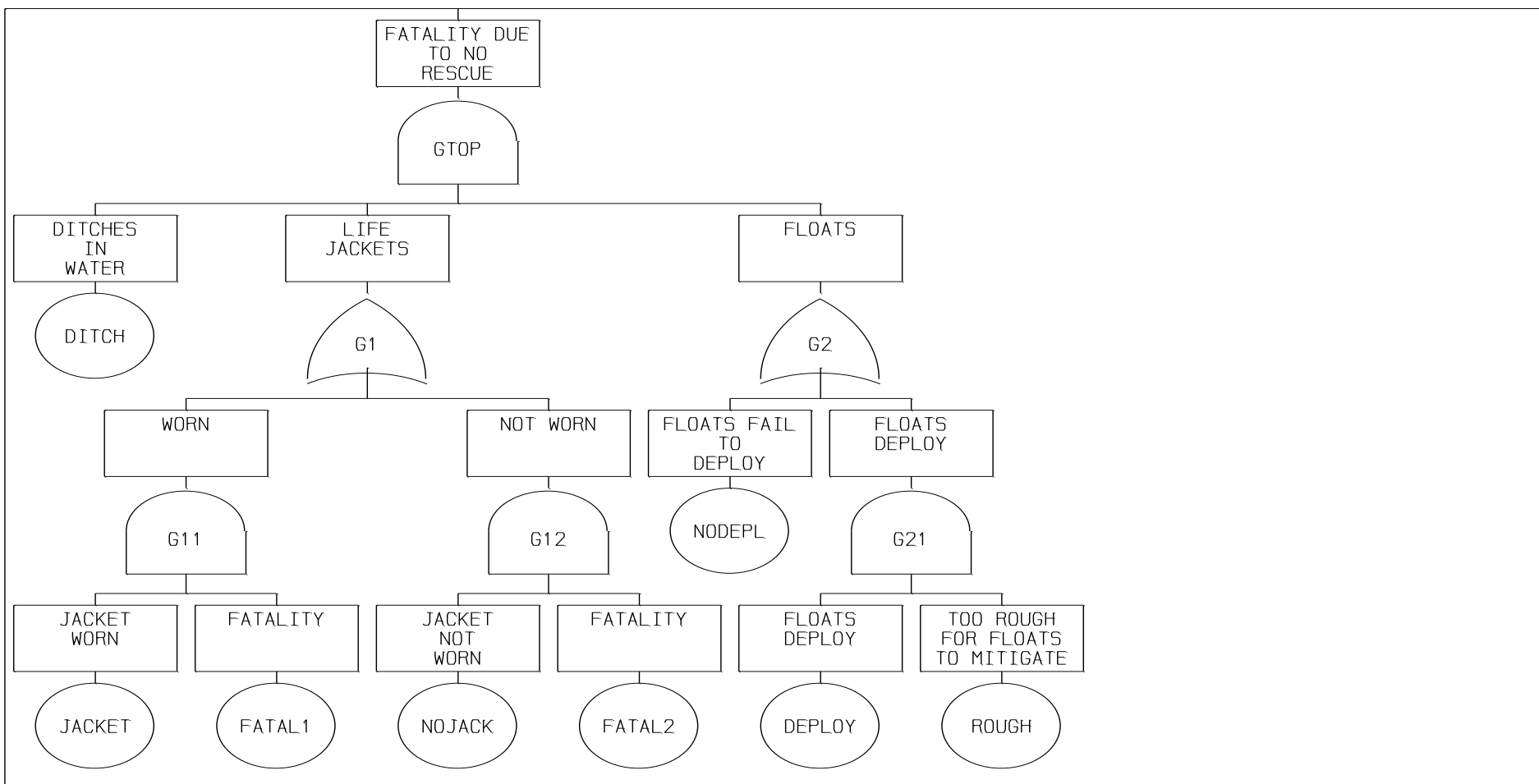
### 3.2.4 Recommendation

The fitting of floatation equipment shall be optional.

**FIGURE 3.2a- FAULT TREE – INVOLVING NO FLOATATION EQUIPMENT**



**FIGURE 3.2b- FAULT TREE – INVOLVING FLOATATION EQUIPMENT**



#### 4. FAILURE RATE and INCIDENT DATA

In this study the FARADIP.THREE Version 6.4 (ref 5.1) data ranges have been used for some of the items. In compiling the FARADIP ranges /and modes, over 30 diverse sources have been consulted. FARADIP data is expressed as ranges. F3 refers to FARADIP.THREE.

ITEM	FAILURE RATE pmh (Total)	MODE	F RATE per 10 <sup>6</sup> hr (Mode) (PFD)	SOURCE
Mobile phone	5	fails	3	F3 Pessimistic judg't
ELT	5	fail to Tx	3	F3 Pessimistic judg't
ELT Sensor (see vibration)	2.5	fail to activate	1	F3
PLB	5	fail to Tx	3	F3 Pessimistic judg't
Lithium Battery	0.5	fails	0.3	F3
Floatation equipment		fail to deploy	(0.1)	Judge
			<b>Per hour</b>	
Forced landing			3.2 10 <sup>-5</sup>	From ref 5.7*
Ditching (water)			2.4 10 <sup>-8</sup>	From ref 5.7**
Exposure per pilot (195pa & 1 hour sortie x 80% away)			1.8 10 <sup>-2</sup>	Ref 5.7 papers***

\* 27 forced landings in 834,304 hours

\*\* 4284 m/c years with one possible ditching infers a 2.4 10<sup>-8</sup> pa rate at 60% confidence (method explained in ref 5.2). Note that the 4,284 m/c years statistic is ONLY registered m/cs and is therefore grossly pessimistic. Appendix 2 references the ditching was inshore.

\*\*\* Based on 126 reports of "last 90 days" experience and assuming 80% of sorties are significantly away from the airfield.

## **5. REFERENCES**

- 5.1 FARADIP.THREE Version 6.4 Failure Rate Data Base, Technis ISBN 0 9516562 3 6.
- 5.2 Reliability, Maintainability and Risk, 7th Edition, D J Smith, Butterworth Heinemann ISBN 0750666943.
- 5.3 Technis report T290 – Individual Maximum Tolerable Risk of Fatality and Cost per Life Saved Criteria.
- 5.4 “Reducing Risks, Protecting People, HSE’s decision making process”, HSE Books, 2001.
- 5.5 TTREE Version 3.3 User's Manual, 1997, Fault Tree package ISBN 09516562 4 4.
- 5.6 Helicopter Club of Great Britain advisory note (undated) re EASA consultation document NPA 2009-02b pages 41-46 & 197-205 - Proposed Rules.
- 5.7 Technis report T419 – R22/44 Incidents 1976-2007.
- 5.8 Technis report T381 – Evaluation of Fuel Dipping Scenarios R22.

## APPENDIX 1 - FAULT TREE DETAILS

### 3.1a NO ELT

TTREE version 3.3

File name: T470AA.TRO

Results of fault tree quantification for top event: GTOP

Top event frequency = 0.982E-08 per hour  
**0.860E-04 per year**

Top event MTBF = 0.102E+09 hours

0.116E+05 years

Top event MDT = 0.500E+00 hours

Top event probability = 0.491E-08  
 (PFD)

#### ----- Basic Event Reliability Data

Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability
FATAL	E			.750
PLTHRS	I/E	.180E-01	1.00 (MDT)	
ALIVE	E			.100
FORCED	I/E	.320E-04	1.00 (MDT)	
TERR'N	E			.250
RADIO	E			.600
INCAP	E			.660
CAP	E			.330
PLBNOT	E			.250
PLBOK	E			.750
LIBAT1	I/E	.300E-06	.438E+04 (PTI)	
PLBF	I/E	.300E-05	.438E+04 (PTI)	
NOMOB	E			.100
MOBF	I/E	.300E-05	168. (PTI)	
ORANGE	E			.750
VAGUE	E			.500

#### ----- Barlow-Proschan measure of cut set importance

Rank 1 Importance .856 MTBF hours .119E+09 MTBF years .136E+05

Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability
PLTHRS	I/E	.180E-01	1.00 (MDT)	
FORCED	I/E	.320E-04	1.00 (MDT)	
TERR'N	E			.250
ALIVE	E			.100
INCAP	E			.660
RADIO	E			.600
FATAL	E			.750

Rank 2 Importance .802E-01 MTBF hours .127E+10 MTBF years .145E+06

Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability
PLTHRS	I/E	.180E-01	1.00 (MDT)	
FORCED	I/E	.320E-04	1.00 (MDT)	
TERR'N	E			.250
ALIVE	E			.100
CAP	E			.330
PLBNOT	E			.250
ORANGE	E			.750
RADIO	E			.600
FATAL	E			.750

Rank 3 Importance .535E-01 MTBF hours .190E+10 MTBF years .217E+06

Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability
PLTHRS	I/E	.180E-01	1.00 (MDT)	
FORCED	I/E	.320E-04	1.00 (MDT)	
TERR'N	E			.250
ALIVE	E			.100
CAP	E			.330
PLBNOT	E			.250
VAGUE	E			.500

	RADIO	E			.600		
	FATAL	E			.750		
Rank	4	Importance	.107E-01	MTBF hours	.952E+10	MTBF years	.109E+07
	Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval		Constant Probability	
	PLTHRS	I/E	.180E-01	1.00	(MDT)		
	FORCED	I/E	.320E-04	1.00	(MDT)		
	TERR'N	E				.250	
	ALIVE	E				.100	
	CAP	E				.330	
	PLBNOT	E				.250	
	NOMOB	E				.100	
	RADIO	E				.600	
	FATAL	E				.750	

Rank	5	Importance	.270E-04	MTBF hours	.378E+13	MTBF years	.431E+09
	Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval		Constant Probability	
	PLTHRS	I/E	.180E-01	1.00	(MDT)		
	FORCED	I/E	.320E-04	1.00	(MDT)		
	TERR'N	E				.250	
	ALIVE	E				.100	
	CAP	E				.330	
	PLBNOT	E				.250	
	MOBF	I/E	.300E-05	168.	(PTI)		
	RADIO	E				.600	
	FATAL	E				.750	

### 3.1b WITH ELT

TTREE version 3.3  
 File name: T470A.TRO  
 Results of fault tree quantification for top event: GTOP  
**Top event frequency = 0.125E-08 per hour**  
**0.110E-04 per year**  
 Top event MTBF = 0.798E+09 hours  
 0.911E+05 years  
 Top event MDT = 0.500E+00 hours  
 Top event probability = 0.627E-09  
 (PFD)

#### Basic Event Reliability Data

Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability
FATAL	E			.750
PLTHRS	I/E	.180E-01	1.00 (MDT)	
ALIVE	E			.100
FORCED	I/E	.320E-04	1.00 (MDT)	
TERR'N	E			.250
RADIO	E			.600
INCAP	E			.660
CAP	E			.330
PLBNOT	E			.250
PLBOK	E			.750
LIBAT1	I/E	.300E-06	.438E+04 (PTI)	
PLBF	I/E	.300E-05	.438E+04 (PTI)	
NOMOB	E			.100
MOBF	I/E	.300E-05	168. (PTI)	
ORANGE	E			.750
VAGUE	E			.500
NOACT	E			.100
ELT	I/E	.300E-05	.438E+04 (PTI)	
SENSOR	I/E	.100E-05	.876E+05 (PTI)	
LIBAT2	I/E	.300E-06	.438E+04 (PTI)	

Barlow-Proschan measure of cut set importance

Rank	1	Importance	.670	MTBF hours	.119E+10	MTBF years	.136E+06
Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability			
PLTHRS	I/E	.180E-01	1.00 (MDT)				
FORCED	I/E	.320E-04	1.00 (MDT)				
TERR'N	E				.250		
ALIVE	E				.100		
INCAP	E				.660		
RADIO	E				.600		
NOACT	E				.100		
FATAL	E				.750		
Rank	2	Importance	.281	MTBF hours	.284E+10	MTBF years	.324E+06
Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability			
PLTHRS	I/E	.180E-01	1.00 (MDT)				
FORCED	I/E	.320E-04	1.00 (MDT)				
TERR'N	E				.250		
ALIVE	E				.100		
INCAP	E				.660		
RADIO	E				.600		
SENSOR	I/E	.100E-05	.876E+05 (PTI)				
FATAL	E				.750		
Rank	3	Importance	.438E-01	MTBF hours	.182E+11	MTBF years	.208E+07
Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability			
PLTHRS	I/E	.180E-01	1.00 (MDT)				
FORCED	I/E	.320E-04	1.00 (MDT)				
TERR'N	E				.250		
ALIVE	E				.100		
INCAP	E				.660		
RADIO	E				.600		
ELT	I/E	.300E-05	.438E+04 (PTI)				
FATAL	E				.750		
Rank	4	Importance	.440E-02	MTBF hours	.181E+12	MTBF years	.207E+08
Basic Event	Type	Failure Rate	Mean Downtime/ Test Interval	Constant Probability			
PLTHRS	I/E	.180E-01	1.00 (MDT)				
FORCED	I/E	.320E-04	1.00 (MDT)				
TERR'N	E				.250		
ALIVE	E				.100		
INCAP	E				.660		
RADIO	E				.600		
LIBAT2	I/E	.300E-06	.438E+04 (PTI)				
FATAL	E				.750		

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**APPENDIX 2 – BRIEF ANALYSIS OF FORCED LANDING TERRAIN**

R22							Hostile Terrain				
2	17/05/98	OSEE				2		Fuel vent kinked			
2	12/06/98	OTIA				2		Fuel line kink prevented flow from main to Aux			
2	22/09/08	BZYE			1	2		Suspected overspeed on previous day			
5	13/07/02	VFSI	2			5	YES	Tail cone struck by rotor in flight 1500'			
6	16/09/95	XIIX				6		Carb heat ON + lever lowered			
6	23/04/96	BROX				6		Forced landing			
6	16/01/97	BOEY	1			6		Unknown but likely icing			
6	12/08/00	BYHD				6		Heavy landing			
6	13/10/04	BYTD			1	6	YES	Heavy landing			
6	30/10/06	OLIZ			1	6		Carb ice			
7	11/11/04	TGRR	1			7		Bad weather			
11	09/03/98	BUIW	1			11		Possible sprag clutch failure			
11	26/05/98	BOAM				11		Sprag clutch			
11	14/05/02	IORG				11		Rotor blade cracked - fatigue			
11	15/11/04	DERB				11		Rotor blade cracked - stres from hinge			
14	02/12/00	BNUZ	2			14		Unknown - possible icing			
14	26/08/05	CBPT				14		Belts believed - m/c not recovered from sea			
R44											
5	30-Jul-03	OUEL	1			5		Mast bump and break up in weather			
6	10/04/03	NIOL			1	6		Probable icing			
7	19/04/98	POWE	4			7	YES	Weather, icing, disorientation ?			
7	24/11/98	WMCN		2	1	7	YES	Weather			
7	01/02/00	TLME	3			7	YES	Rollover - restricted area - line strike			
7	16/09/06	GGRH			2	7		Fog			
7	03/08/07	OSSI	4			7	YES	Weather			
11	16/12/06	CEFR				11		Gearbox mounts - vibration			
16	19/10/02	URUH			1	16		Fuel - unknown reason for discrepancy			
16	04/02/06	HEPY				16		Water in fuel (through fuel caps)- heavy landing			

a) 6 out of 27 represents approximately 25%. Note that the R22 is 20% and the R44 is 55%.

b) CBPT is the one case of ditching.