Part 4: Systems Engineering

Task 1: System Level Requirement

ID	Requirement Text	Rationale Text	Verification Type	Verification Plan
P-1	The TUAV system shall have a radio transmission range of 14km.	Statistical Analysis shows that for 14km the probability of the system working is 95.8% according to the data given.	Testing	Find the point where the transmission becomes weak while moving the receiver away from the transmitter. It should be greater than 14km.
P-2	The TUAV system shall hover for a mission endurance of 2 hours.	Data in the brief shows that each SARH mission is 2 hours.	Testing	Record the flight time for a test flight and ensure it can endure 2 hours of flight.
P-3	The TUAV system shall hover at an altitude of 300 m.	Using the data, it is shown that for an altitude of 300 m, the CDF shows a probability of 0.99.	Testing	Testing the hover capabilities at the maximum required altitude.
P-4	The TUAV system shall have a reliability of 0.999.	The radio relay sub-system has a reliability of 0.999 and the TUAV system depends on this.	Analysis	Calculate the failure rate to find the reliability of the system.
E-1	The TUAV system shall operate at a maximum windspeed of 17m/s.	Comparing the Douglas Sea State with the Beaufort Scale, the maximum wind speed for the worst sea state of 6 is 17m/s. [17] [18]	Testing	Test the system in a wind tunnel with speeds up to 17m/s.
E-2	The TUAV system shall operate at a minimum temperature of 0°C.	South England’s mean temperature data shows that it goes to 0°C near coastal areas [19].	Testing	Carry out tests on the components of the TUAV system at 0°C.
E-3	The TUAV system shall operate at a maximum temperature of 40°C	Most electric components have a max temp of 40°C [20].	Testing	Carry out operational tests at 40°C.
I-1	The TUAV aerial platform shall be stored in the storage envelope of 0.5x0.5x0.5 in the ILB.	This is so that the aerial platform can fit onboard the ILB.	Inspection	Measure the dimensions of the aerial platform to ensure it does not exceed the 0.5m limit on the length, width, and height.
I-2	The tethering equipment shall be stored in the storage envelope of 0.25x0.5x0.25 in the ILB.	So that the tethering equipment can be fitted onboard the ILB.	Inspection	Measure the dimensions of the tethering equipment to ensure it does not exceed 0.25m in length and height, 0.5m in width.
I-3	The battery shall be stored in the storage envelope of 0.25x0.25x0.25 in the ILB.	This is so that the battery can fit onboard the ILB to provide power to the TUAV.	Inspection	Measure the dimensions of the battery to ensure it does not exceed the 0.25m limit on the length, width, and height.
V-1	The TUAV system shall operate beneath vibration of 8.5g and 5-10 Hz	To ensure the safety of the personnel onboard the ILB, the system shall not exceed the requirements stated.	Testing	Test the acceleration frequencies by launching the TUAV from the ILB at different sea states.

Additional research and sources

P-1: The range was obtained by using Equation 1 with the provided longitude and latitude data that are in degree coordinates.

$$cos^{-1}(\sin(LatL) * \sin(LatI) + \cos(LatL) * \cos(LatI) * \cos((LongI) - (LongL)) * 6371 \quad (1)$$

Where LatL and LongL was the latitude and longitude of the lifeboat station respectively and LatI and LongI was the latitude and the longitude of the incident respectively. The range was calculated in km and an exponential distribution was used and showed the best fit as seen in Figure 4.1.1 below.

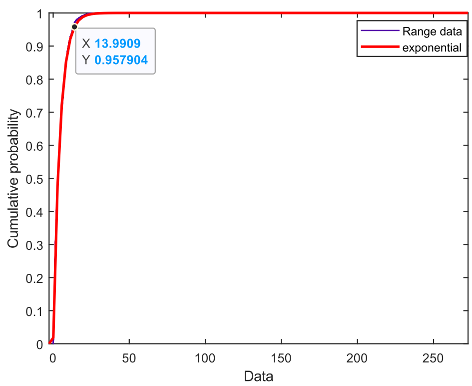

Figure 4.1.1: Cumulative Density Function graph of the Range for P-1

P-3: The terrain height data was used due to it having higher values than transmission height, although the transmission height data had to be cleaned as it contained negative elevation values. A Weibull distribution was used to find that at 300 meters the probability was 0.987. It shows the best fit as seen below in Figure 4.1.2

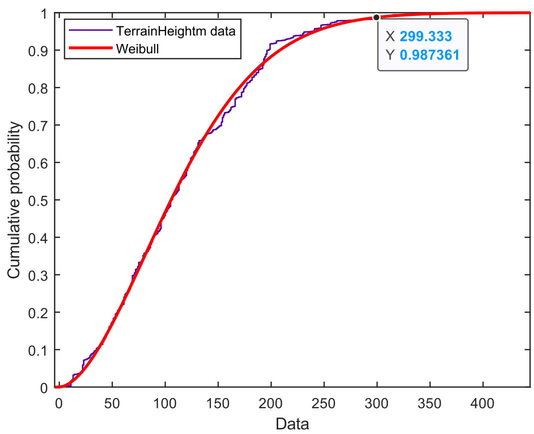

Figure 4.1.2: Cumulative Density Function graph of the Terrain Heights for P-3

E-1: To ensure that the TUAV system works in the worst state, the Douglas Sea State of 6 was chosen, the maximum height of the waves at this sea state range from 4 to 6 meters. To obtain the windspeeds at this range of wave heights, the Beaufort scale was used. A sea state of 6 corresponds to a Beaufort wind scale value of 7 which has a range of windspeeds from 14-17m/s. Hence the upper limit of 17m/s is chosen for the maximum windspeed that the system shall work at.

E-2: The temperature data was found for South England from the Met Office and the minimum and maximum mean temperature data was used to find the ranges of temperature the TUAV system shall operate in. The minimum temperature was found to be 1°C and the maximum to be 35°C [19]

Task 2: Tethering Sub-System Functional and Architectural Description

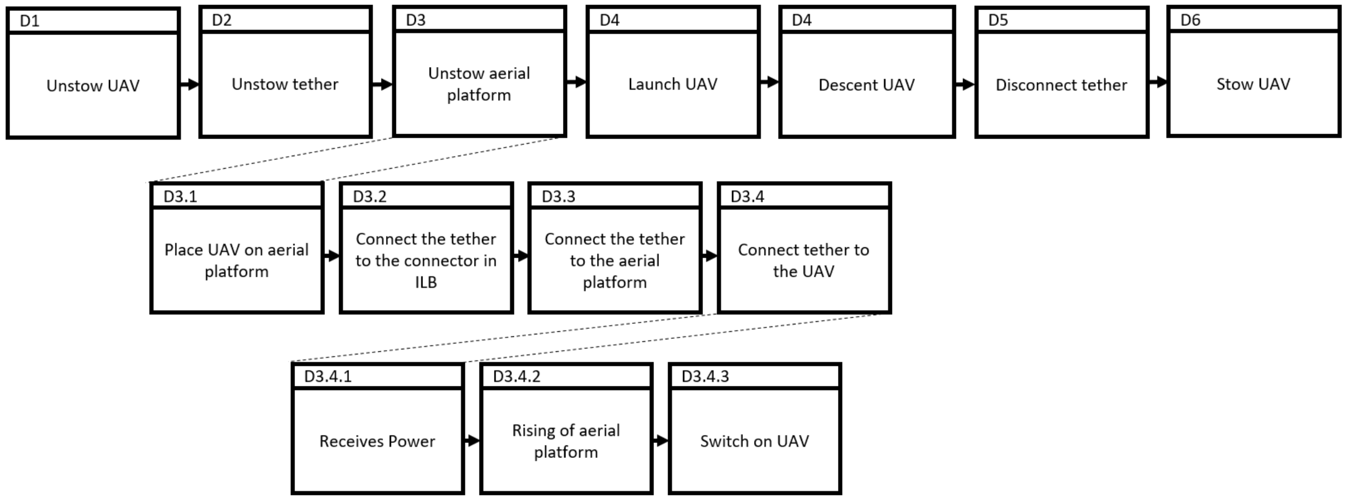

Figure 4.2.1: Functional Flow Block Diagram of the Tethering Sub-System

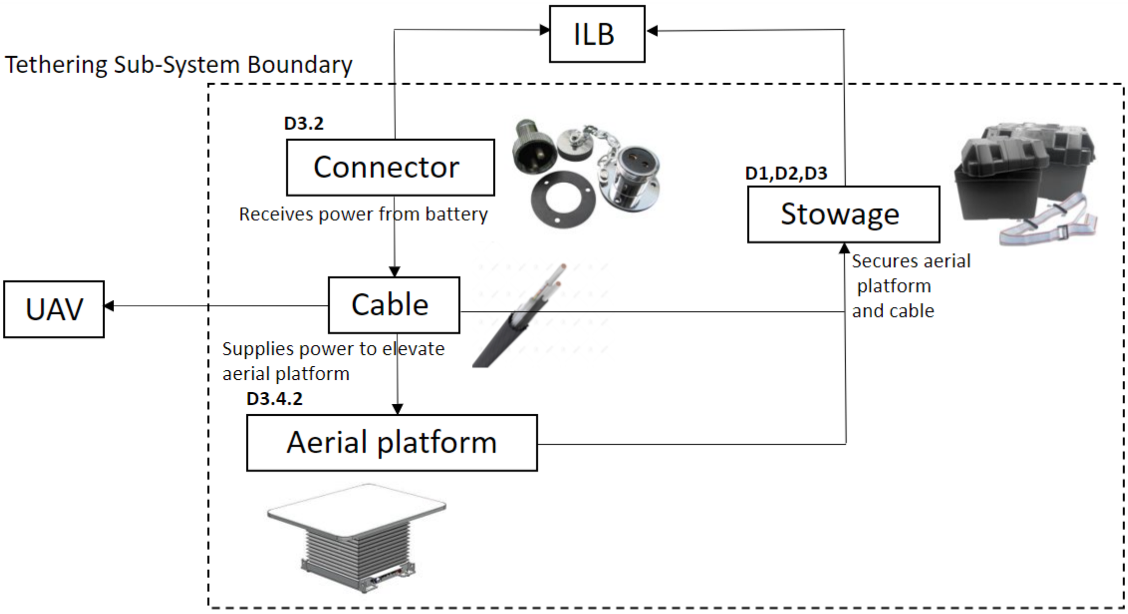

Figure 4.2.2: System Architecture of Tethering Sub-System with labels relating back to the FFBD

Table 4.2.1: FMECA of Tethering Sub-system

Sub-system	Failure mode	Effect	Affected sub-system	Occurrence	Severity	Detectability	RPN
Tether	Stowage failure	Slight damage of the sub-system/damage during transport	UAV	2	3	5	30
	Knotted tether	UAV cannot reach required altitude	UAV	4	3	2	24
	Rupture of tether	Loss of UAV	UAV	3	5	4	60
	Connector disconnects from ILB	Power loss in UAV	UAV	4	5	5	100
	Aerial platform does not rise	Take off from lower height	Radio	4	5	4	80

The two most critical failure modes are the instances where the connector disconnects from the ILB and if the aerial platform does not rise. The connector disconnecting from the ILB is a major concern because the tether, aerial platform and UAV all receive power from the battery on the ILB. This results in a failure of receiving power if the connector gets disconnected which means the whole mission is compromised as the UAV would plunge to the bottom if there were no power supplied to it. It may occur if a member of staff accidentally bumps into it during the mission if there are bad weather conditions or if it gets loosened by the acceleration of the ILB during the mission and many other ways. To mitigate this critical failure mode, security measures can be taken to ensure that the connector is securely fastened to the ILB. For example, an extra component that fastens the connector to the ILB and also the cable, as seen in the system architecture diagram in Figure 4.2.2 above, could be implemented. Additionally, a sensor could be implemented to which if the connector is disconnected, an alarm will ring to alert members of staff on the ILB to immediately reconnect it before the UAV completely falls into the ocean in the case that is disconnects mid-mission.

In the case that the aerial platform does not rise, the UAV will have to launch from a lower height. This is not a major concern in terms of it being able to launch. However, since the tethering cable is 300m and the transmission height takes into consideration the heightened aerial platform this would mean that if the platform does not rise, the cable would not be long enough to reach the required altitude for communication with the cooperating assets. This would be critical for the mission because the purpose of the mission is to communicate with the lifeboat station and the rescue team. If the UAV cannot reach the height it needs to in order to relay the information, then the whole mission is compromised. A way to mitigate the effect of this failure mode is to increase the length of the tethering cable. There could be a safety factor implemented where the length will be a certain amount longer than the required height that it is needed to reach for communication. This way, if the aerial platform does not rise, the UAV can take off from any flat surface on the lifeboat and still reach the required altitude with the longer tethering cable.

Task 3: TUAV MBSE

Requirements and Constraints	Radio transmission range	Hover altitude	Airframe Sub-system Mass	
Radio sub-system reliability	**Radio Sub-system**	Radio Transmitter Power	Radio Sub-system Mass	Radio Transmitter Power
		Cable Sub-system	Cable Sub-system Mass	Cable Power Loss (Sub-system Power)
		Propulsion Sub-System Power	**Propulsion Sub-system**	Propulsion Sub-System Power
Hover endurance				**Power Storage Budget**

Figure 4.3.1: N^2 Diagram of the TUAV MBSE

Table 4.3.1: Mass-Budget Table of the TUAV System

Component	Unit mass (kg)	Margin	Mass Margin (kg)
BigRad-10W	0.4	0.05	0.42
BigRad-10W	0.4	0.05	0.42
Magπ Sense	0.2	0.05	0.21
Magπ Switch	0.1	0.05	0.105
Sub-system estimated mass			1.155
Sub-system total mass with margin		0.2	1.386
Cable Mass		-	3
Airframe Mass		-	2
Total system mass			6.386

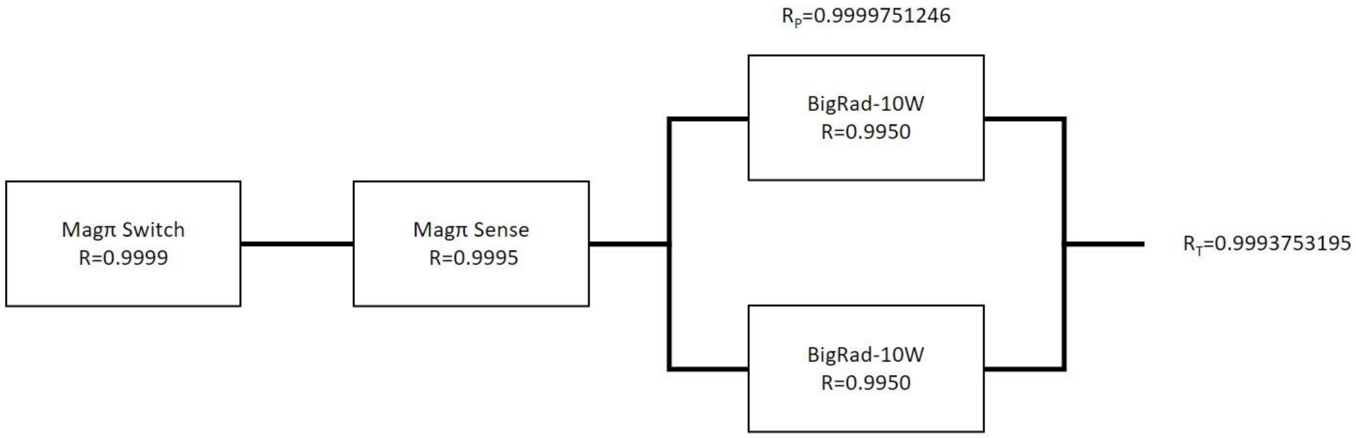

Figure 4.3.2: Reliability Block Diagram of the Radio Sub-System

Table 4.3.2: Requirements Table

Requirements	Requirement Value	Requirement Satisfied	System Value
Hover Altitude (m)	300	Constraint	300
Radio Transmission Range (km)	14	YES	15450.9681
Hover Endurance (Hr)	2	YES	2.13574139
Radio Sub-System Reliability	0.9999	NO	0.99937532

The requirement that is not satisfied in this system configuration is the radio sub-system reliability. The system element that caused this is the Transmitter. As seen in Table 4.3.2 above, the system value is 0.99937 however the requirement value is 0.9999. This requirement value was based on the brief as it mentioned that it had to be one order of magnitude higher than the customer requirement of 0.999. The system value was obtained by the Reliability Block Diagram shown in Figure 4.3.2 above. The difference between the system value and requirement is approximately 0.0005. This shows that this radio sub-system configuration has a very low chance of failing. The system need is to relay information between the ILB, lifeboat station, and the cooperating assets (coastguard helicopters, coastguard responders) therefore there is a very high chance that the system will function successfully even though the system value does not meet the customer requirement.

Task 4: System Trade-off Study

Table 4.4.1: Trade-off Study of the 3 proposed system architectures

Metric	Weighting	TUAV	SATCOM	Fixed Wing UAV
Cost	0.3	4 [1.2]	1 [0.3]	3 [0.9]
Bandwidth	0.4	2 [0.8]	5 [2.0]	2 [0.8]
Ease of infrastructure implementation	0.2	3 [0.6]	4 [0.8]	1 [0.2]
Reliability	0.1	4 [0.4]	2 [0.2]	4[0.4]
Score MOP		**3.0**	**3.3**	**2.3**

Table 4.4.2: Definition of max/min score ranges

Metric	Scores	Definitions
Bandwidth	1	Low bandwidth means less data transmission for a given time
	5	High bandwidth means more data transmission
Cost	1	Higher cost of system overall
	5	Lower cost of system overall
Reliability	1	System has overall lower frequency of maintenance
	5	System has overall higher frequency of maintenance
Ease of infrastructure implementation	1	Build completely new infrastructure for the system
	5	Can use existing infrastructure with less modifications

Definition & justification of metric: Installation cost, bandwidth, infrastructure implementation and reliability were the four metrics chosen to compare the three different systems. Installation costs are the costs incurred for implementing the system. This includes the capital expenditure (CAPEX), and the operational costs of the system (OPEX). Cost is important metric because the organisation has a budget to spend on this project that needs to be followed. Bandwidth is defined as the amount of data travelled in between communication channels. A higher bandwidth will increase the performance of communications as more data is being transferred in a given amount of time. High bandwidths provide enhanced situational awareness due to more information such as precise location data and incident details being relayed. Reliability is defined as the amount of maintenance the system needs to function efficiently. Reliability is required in every system as functionality reduces with each usage. Needing regular maintenance costs more and reduce the systems lifespan Reliability is important because this system is used in critical applications and needs to operate without failures or malfunctions. By frequently maintaining, the system reliability can be increased. Infrastructure implementation is an essential category as these systems need various modification of the current system. It is defined as the ease of building or modifying new infrastructure in the existing one. Infrastructure implementation was chosen because changes need to be made to the existing lifeboat stations and implementing a new system will incur additional costs and training to the search team. The score for each metric is shown in Table 4.4.2; a higher score means it is better for the system in terms of that specific metric.

Definition and justification of weighting: The highest weighted metric was chosen by assessing what satisfies the customer requirements the most which is increasing the bandwidth of the system. This is because increased bandwidth is marginally prioritised over costs in MSAR missions according to the stakeholders. Following this, cost of the whole system is the next highest metric as the company needs to be able to afford the purchase and upkeep of the system chosen. Ease of infrastructure implementation is the 3rd highest metric as there are tests that need to be carried out to ensure the infrastructure of the system passes the respective tests and it also costs money to build a whole new infrastructure. The reliability is the last metric because it is still an important metric however it is already taken into consideration in the RBD so this reliability is mainly the maintenance of the system.

The trade-off study shows that the SATCOM has the highest score MOP of 3.3 suggesting that it could be a better system to implement in terms of the metrics stated. It has the highest overall cost of $3,000,000 for CAPEX & OPEX The next is the TUAV system with a score MOP of 3.0 and the last is the Fixed Wing UAV with score MOP of 2.3. this shows that the TUAV system is a good point in between the two other proposed systems, and it has the lowest overall cost of $145,000. SATCOM has the lower reliability score because overall it is maintained 60 times over 5 years however the TUAV and FW-UAV are maintained 180 times over 5 years. However, the cost of maintaining the SATCOM is approximately 10 times more than the costs for the TUAV and FW-UAV.