Aerostar UAS
Failure Modes and
End Effect Criticality (FMECA)
Report

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1. INTRODUCTION

1.1. Scope

This report covers the Failure Modes Effect and Criticality Analysis (FMECA) for the Aerostar UAS, including UAV, MCS and the Communication modules.

This analysis was prepared using the functional approach down to the component level. The analysis was conducted by using CARE®-FMECA software (Computer Aided Reliability Engineering) developed by BQR Reliability Eng. Ltd. Israel.

1.2. Purpose

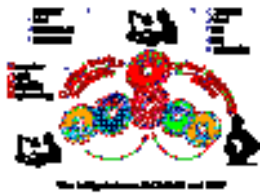
The purpose of the FMECA as an engineering analysis tool is to assess high-risk items. It is also employed to define special test considerations, quality inspection points, operational constraints, useful life and other pertinent information and activities necessary to minimize failure risk. The FMECA forms an integral part of all reliability, maintainability, safety and ILS activities.

This FMECA was prepared in order to study and analyze potential failure modes of each component and to evaluate their effect on the system overall performance. The failure modes are then classified according to their severity.

1.3. Acronyms and Notations

CARE - Computer Aided Reliability Engineering

FMECA - Failure Modes Effects and Criticality Analysis



2. REFERENCED DOCUMENTS

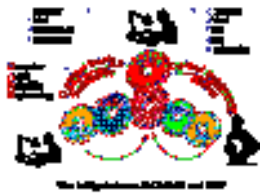
The following documents were employed in the preparation of this FMECA report although they may not be specifically referenced in the contents of this report.

2.1. Customer Documents

- Aerostar UAS Schematics.
- Aerostar UAS block diagrams and explanations.
- Aerostar UAS MTBF Report.

2.2. Other Documents

- MIL-STD-1629A, Procedure for performing FMECA.
- Mil-Hdbk-S217F-N2 Reliability prediction model.
- FMD-91 standard.
- CARE (Computer Aided Reliability Eng.) software and User's Manual by BQR.



3. ANALYSIS APPROACH

3.1. Analysis Method

The FMECA was performed in 2 steps:

1. Failure modes definition for each component.
2. Failure modes propagation bottom up.

Each failure mode was analyzed to check its possible effects on the system's End Effects. The approach used to perform the FMECA for the system was bottom up, using functional approach.

For each component all possible failure modes were defined individually as to analyze their impact on the functional performance of the system.

3.2. Classifications

3.2.1. Severity Classifications

To each identified failure mode a severity classification is assigned according to its end effect. The severity level definitions associated with the system failure modes are in Para. 4.1.

3.2.2. Criticality Classifications

The following is the definition of the criticality levels that were used to classify the Aerostar UAS End Effects.

a. **Level A:** Frequent - Criticality is assigned to each End Effect that contributes 20% or more of the total failure rate.

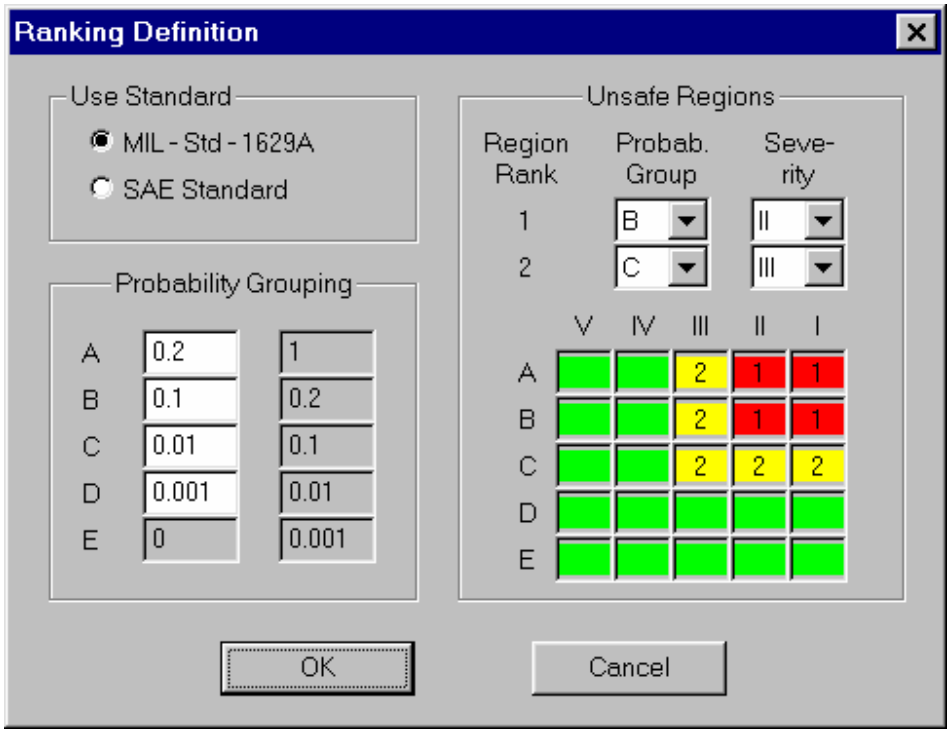
b. **Level B:** Reasonably Probable - Criticality is assigned to each End Effect that contributes more than 10% but less than 20% of the total failure rate.

c. **Level C:** Occasional - Criticality is assigned to each End Effect that contributes more than 1% but less than 10% of the total failure rate.

d. **Level D:** Remote - Criticality is assigned to each End Effect that contributes more than 0.1% but less than 1% of the total failure rate.

e. **Level E:** Extremely Unlikely - Criticality is assigned to each End Effect that contributes less than 0.1% of the total failure rate.

3.2.3. Unsafe Region Definition



3.3. FMECA Worksheet Reports

The FMECA worksheets are prepared in accordance with the guidelines and requirements of MIL-STD-1629A, except as modified by this document.

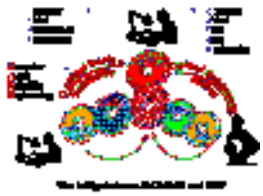
1. Failure Modes Effect and Criticality Analysis Report (Appendix A) - The FMECA table provides a means of relating failed items to end-effects, following the failures propagation through all the project functional blocks.
2. Mode Criticality List – Cm (Appendix B) – The MCL matrix provides the sum of failure modes in each region, criticality vs. severity data.

3.3.1. Criticality Values

The following is an explanation of the formula used for the calculation of the criticality values.

a. Failure Mode Ratio (α). The failure mode ratio is the relation between the considered Mode Rate for the particular failure mode and the function failure rate.

b. Failure Effect Probability (β). The failure effect probability is the conditional probability



that the failure effect will result in the identified criticality classification, given that the failure mode occurs.

c. Failure Mode Criticality Number (Cm). Cm is the portion of the criticality number for the function due to one of its failure modes under a particular severity classification. For a particular severity classification and operational phase, the Cm for a failure mode may be calculated with the following formula:

$$Cm = \beta\alpha\lambda_p t$$

Where:

Cm = Criticality number for a failure mode.

β = Failure effect probability.

α = Failure mode ratio.

λ_p = Mode failure rate($*10^{-6}$).

t = Duration of applicable mission phase.

d. Item Criticality number (Cr). Cr is the probability of event of failures of a specific type expected due to the function's failure modes. The specific type of failure is expressed by the severity classification for the function's failure modes. For a particular severity classification and mission phase, the Cr for a function is the sum of the failure mode criticality numbers, Cm, and may also be calculated using the following formula:

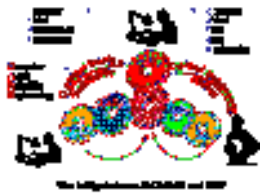
$$Cr = \sum_{n=1}^{j} (\beta\alpha\lambda_p t)n$$

Where:

Cr = Criticality number for the function.

n = The failure modes of the function that fall under a particular severity classification.

j = Last failure mode of the item under the severity classification.



4. Results and Summary

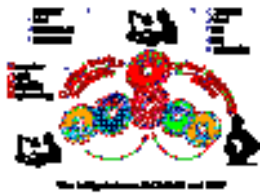
4.1. End-Effects Phase Criticality

Table 1 presents the End Effects which where defined for the system and their numeric results for a Mission Phase Time = 12 hours.

Table 2 presents the Severity Rates Summary.

##	End Effect Name	Severity	System Failure Rate [F/10^6Hrs]	End Effect Ratio (Alpha)	End Effect Rate [F/10^6Hrs]	End Effect Ratio for Severity	End Effect Probability H=1-exp(-f*t)
a	b	c	d	e	f	g	h
1	UAV loss of control	II	1743.39	0.003155	5.50062	1.000000	6.60053E-005
2	Fail, but UAV can return safely	IV	1743.39	0.996845	1737.89	1.000000	0.0206387
Total				**1.000000**	**1743.39**		

Table 1: End Effect Report



- The end-effects criticality is a summary of all the failure modes criticality that caused this End Effect. End Effect's criticality and probabilities where calculated from all the Failure Modes ratios.
- Table 2 represents the definition of severities as they are described in the Mil-Std-1629A
- The results in the Table 2 are taken from the FMECA analysis based on the UAS modeling that was performed by BQR Reliability Engineering LTD.

Severity	Severity Rate [F/10^6Hrs]	Ratio [%]	Severity Description
i	j	k	l
I	---------	------	Catastrophic - A failure which may cause personal danger or system loss.
II	5.50062	0.32	Critical - A failure which may cause severe hit, major property damage, or major system damage which will result in mission loss.
III	---------	------	Marginal - A failure which may cause minor hit/property/system damage which will result in delay or lost of availability or mission degradation.
IV	1737.89	99.68	Minor - A failure not serious enough to cause injury, property damage, or system damage, but which will result in unscheduled maintenance or repair.
V	---------	------	User defined.
Total	**1743.39**	**100.00**	-

Table 2: Criticality Summary

Titles of End Effects Report (tables 1 and 2)

a	Sequential number.
b	Name of the system failure mode
c	Severity value: one of severity numbers according to definitions in the severity description table.
d	System Failure Rate: number of failures per million hours.
e	End Effect Ratio (Alpha) - the relation between the considered end effect rate and the system failure rate.
f	End Effect Rate – collection of all failures (per 1000000 hours) having the specific end effect.
g	End Effect Ratio for a Severity = End Effect Rate/ Severity Rate, where Severity Rate is the sum of EE Rates for EEs with this severity.
h	End Effect Probability = exp(- (EE Rate)*(Mission Time))
i	Severity Rate = sum of EE Rates for EEs with this severity.
k	Ratio(%) = (Severity Rate)/(System Failure Rate) * 100

Table 3: Titles of End Effects Report

- The FMECA presented below in Appendix A discovered the failure modes end-effects and all their sources.
- Refer to Appendix B – Mode Criticality List to see the most critical components and modes.

- Although, according to the selected mission profile, no critical changes are needed, some recommendations to the design were made.
- Please review the "1477-Aerostar-Final Ram report", in order to obtain the full recommendation list.

5. Appendixes

5.1. Appendix A : Failure Modes Effect And Criticality Analysis Report

- Please refer to Aerostar-FMECA_CA.doc appendix in order to obtain the full FMECA report.

Titles of Criticality Analysis Report

a	Block indenture level in the tree.
b	Block sequential number in the tree.
c	Block Reference Designator.
d	Block Function name.
e	Block description.
f	Block FPMH - number of the block failures per million hours.
g	Failure rate source - prediction method or user input.
h	The worst Severity of the block failure modes.
i	Sum of Failure Modes Criticality having this severity.
j	Failure mode name.
k	The mode contribution to the block failure rate.
l	Mode Compensating provision.
m	Detection method description.
n	List of internal failure causes. Internal cause of a failure mode is the cause that does not present another failure mode.
o	Parent or brother block failure mode caused by this failure mode.
p	End Effect Name - the system failure mode.
q	End Effect Severity defined by user in Edit Mode dialog (Edit menu) for the End Effect.
r	Beta - Probability that the failure mode causes the End Effect. Is calculated by the program using next effect probabilities inputted by user.
s	Failure Mode probability = (1 – exp (- Block Failure Rate * Mission Time / 10^6)) * Mode Rate * Beta / Block Failure Rate.
t	Failure Mode Criticality for the End Effect = Block Failure Rate * Failure Mode Ratio * Beta * Mission Time / 10^6. Presents number of failure mode occurrences, which cause the End Effect during the Mission Time.

Table 4: Titles of Criticality Analysis Report

5.2. Appendix B: Mode Criticality List (Cm)

Failure Modes Criticality Matrix (Quantity for Internal Causes only)						
PROBABILITY		SEVERITY				
Group	Range	V	IV	III	II	I
a	b	d				
A	0.2 - 1	0	0	0	0	0
B	0.1 - 0.2	0	0	0	0	0
C	0.01 - 0.1	0	0	0	0	0
D	0.001 - 0.01	0	0	0	0	0
E	0 - 0.001	0	582	0	17	0

Table 5: Mode Criticality List Summary

- Please review the attached file **Aerostar-FMECA_MCL.doc**, to obtain the detailed Mode Criticality Report.

Titles of Mode Criticality List Report

a	Probability group - the identifier of a probability interval.
b	Range: If the above title is 'Probability', the range presents probability intervals defined by user in Ranking Definition dialog (Edit menu). If the above title is 'Part of Overall Probability', the range presents the part intervals of the system Failure Probability.
b-1	If the above title is 'Probability', Criticality range = - ln (1- P)*10^6, where P is the corresponding probability level from the column 'b'. Else Criticality range = Range* System Failure Probability*10^6.
d	Severity levels defined by user in Severity Definition dialog (Edit menu). Each value in the below cells presents the number of failure modes having the corresponding severity and criticality.
e	Emergency Regions defined by user in Ranking Definition dialog (Edit menu).
f	Severity breakdown of the region.
g	Probability Group identifier from Criticality Matrix.
h	Sequential Block Number in the tree.
i	Reference Designator of the block.
j	The block Function
k	Failure Mode Description
l	Name of a Failure Mode having this severity and probability
m	The mode Criticality for this Severity and Probability group - the number of the mode occurrences (* 10^6) during the Mission Time contained in this Criticality interval and causing the System failure of this Severity.
n	Those failures Probability = (1 - exp(- Block Failure Rate * Mission Time / 10^6)) * Mode Criticality / Block Failure Rate.
o	The mode Criticality divided by the Severity Rate (see End Effects Report) and Mission Time.
p	The mode Criticality divided by the System Failure Rate (see End Effects Report) and Mission Time.