Aerostar (UAS)
RAMS
Report

Prepared
For Aeronautics

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Executive Summary

The purpose of this document is to present the RAMS (Reliability, Availability, Maintenance and Safety) analysis for the UAS, including the UAV, MCS and the Communication, and to examine the safety of the UAS to satisfy the ATA requirement so that the UAV can fly over settled area safely with a very low probability to crash, or worse – cause death or injury.

The ATA requirement for UAV's critical failure is 10e-06 per operational hour.

The Aerostar UAS meets those requirements with "UAV loss of control" critical failure with probability of 0.94x10e-06, which is within acceptable level.

The following document represents the final RAMS results and recommendations.

1. SCOPE

1.1. Purpose

The purpose of this document is to present the RAMS (Reliability, Availability, Maintenance and Safety) analysis for the UAS, including the UAV, MCS and the Communication, and to examine the safety of the UAS to satisfy the ATA requirement so that the UAV can fly over settled area safely with a very low probability to crash.

This RAMS analysis will present:

1 The product functional tree.

2 The MTBF for each candidate in the tree.

3 The possible failure modes for each candidate with its effect on the UAS behavior, with special emphasis on safety.

4 Calculating the MTBCF of the UAS.

5 The Fault Tree for "UAV loss of control" which can cause a safety hazard or even crash.

6 The calculation probability for "UAV loss of control"

7 Recommendation to improve the UAS reliability and safety.

1.2. Tools and method

The analysis was done using CARE® software from BQR Israel. The programs that were used are:

1. **CARE-MTBF**: This program presents the hierarchical tree of the assemblies which build up the UAS. Each assembly gets its failure rates (MTBF), either by using prediction method like Mil-HDBK-217 or field data. This program generates the database of candidates that are used latter for the FMECA, FTA and RBD.
2. **CARE-FMECA** (Failure Modes Effects & Criticality Analysis): This program uses the database which the CARE-MTBF generates; defines for each candidate its Failure Modes (FM) and ratio and the effect of each FM on the system's behavior. This program tries to identify single points of failures that will cause "UAV loss of control" End Effect. This program generates the data base of failure modes and effects that are used latter for the CARE-FTA and CARE-RBD.
3. **CARE-RBD** (Reliability Block Diagram): This program calculates the MTBCF by defining the Reliability models for all candidates taking into account only candidates that fail can cancel the UAV's mission. The top level result represents the Critical MTBF of the UAS entire system, including the UAV, MCS and the Communication sub-blocks.

4. **CARE-FTA** (Fault Tree Analysis): This program enables to define hierarchically failure causes and combinations using standard gates (AND, OR etc) that will cause "UAV loss of control". This program calculates the probability of the critical event "UAV loss of control" which can cause the UAV to crash on the ground without any control, while causing environmental danger.

1.3. Analyzed Aerostar Elements

The UAS elements that were analyzed are:

1. UAV
    a. Fuselage
    b. Engine
    c. Electricity
    d. Fuel Tank
    e. Avionics
    f. Optics
2. MCS
    a. IP
    b. MC
    c. PO
    d. External Pilot
3. Communication
    a. Air Communication
        i. Main Channel
        ii. Secondary Channel
    b. Ground Communication
        i. Main Channel
        ii. Secondary Channel

1.4. Terms, Acronyms and Abbreviations

Candidate	Any component or part which is analyzed. A candidate can be a leaf (component which is not disassembled, mostly discarded and not repaired) or an assembly which can be disassembled into smaller assemblies or components, which can be either discarded or repaired.
CBX	Co-Pilot Box
Comm.	Communication block, including Air and Ground communication
FM	Failure Mode/s
FMEA	Failure Mode Effects Analysis
FPMH	Failures Per Million Hours
FTA	Fault Tree Analysis
GMS	Ground multifunction system application
IP	Internal Pilot
MC	Mission Commander
MCS	Mission Control Station
MTBCF	Mean Time Between Critical Failures. In this case only candidates which if fails will stop the UAV mission
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
PBX	Pilot Box
PO	Payload Operator
RBD	Reliability Block Diagram
SBX	Student Box
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
HE	Human Errors

2. REFERENCED DOCUMENTS

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

2.1. Customer Documents

1. Aerostar BOM.xls
2. Engine BOM – 498 PRO.xls
3. MCS Extended BOM.xls
4. GDT General BOM.xls
5. Aerostar drawings (*.dwg)

2.2. Other documents

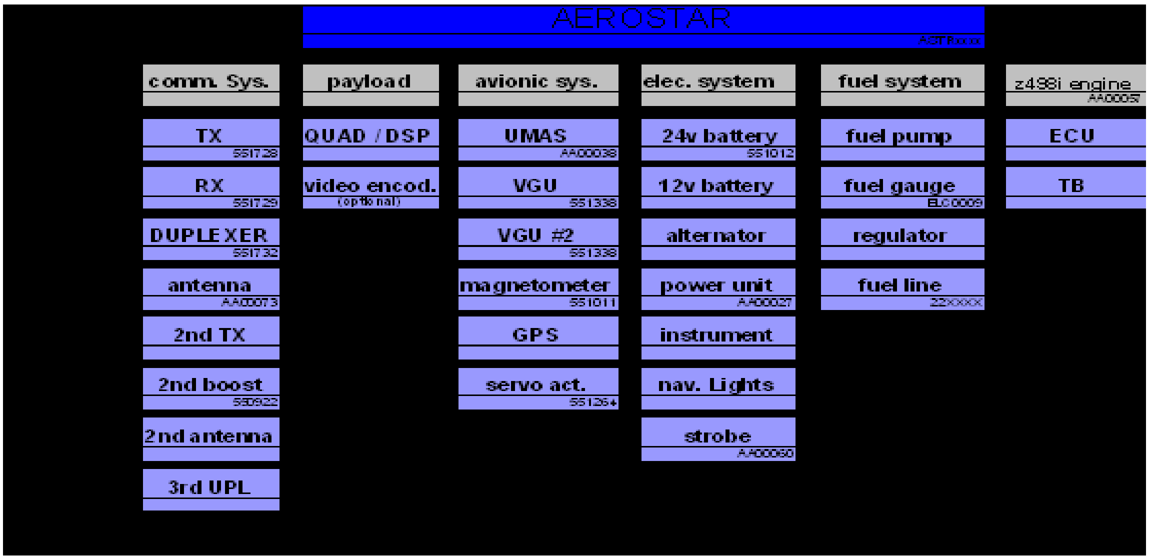
1. 1474-Aerostar MTBF report.doc
2. 1475-Aerostar FMECA report.doc
3. 1476-Aerostar FTA report.doc
4. 1500-Aerostar MTBCF report.doc

2.3. CARE® Files

- AEROSTAR - V10.mtbf
- Aerostar-v11.fmc
- AEROSTAR-v5.rba
- Aerostar.fta
- Cdb3.cdb

3. Aerostar Architecture

3.1. UAV Architecture



3.2. Ground Station

Mission commander bay
14" Video monitor
Video matrix
Intercom
UPS power supply
VHF Communication

EP stand
EP stand
2 Flight boxes
Heaters
2 Intercom units
Stand Lights

Internal operator (pilot) bay
RF drawer
17" System monitor
MCD - control panel
Keboard and mouse
System computer
Power supplier
DVR
Flight box
Backup batteries

Payload operator bay
17" System monitor
14" Video monitor
MCD - Control panel
keboard and mouse
10.4" payload touch screen
System computer
Payload operation computer
Power supplier
Payload keboard and mouse
Backup batteries

4. Analysis Steps

4.1. Reliability Analysis

4.1.1. MTBF Prediction

Preparation of the system's hierarchical product tree using the CARE® -MTBF software.

The hierarchical product tree contains the following parts:

- UAV – Aerostar
- MCS – Mission control station
- Comm. – Communication block, including both the Air and the Ground communication blocks.

4.1.2. Reliability Block Diagram (RBD)

Preparation of the system’s reliability model, using the CARE®-RBD software module.

The reliability model includes all critical components that are necessary for UAS's normal mission operation, taking under consideration all available redundancy in the UAS's system. Such analysis allows calculating the system's MTBCF (Mean Time Between Critical Failures), by taking under consideration all the system's configurations and not assuming serial model structure of the system, as it is used in the MTBF analyses.

4.1.3. FMECA

Analyze the effects of each and every single separate failure using the CARE®-FMECA software module, analyzing their effect on the system level, causing an End Effect of some severity.

The hierarchical tree was transferred to the CARE®-FMECA software module, in order to prepare the functional tree of the UAS system.

In the FMECA analysis all system's critical components were taken under consideration, and all failure modes of those components were considered.

The probability of every failure was propagated to the system level, and used in order to create a criticality matrix of the system, which includes the probability and the severity of each and every single failure.

The functional tree was later used for preparing the Fault Tree model (FTA).

4.1.4. FTA

The CARE®-FTA software module was used in order to prepare the model of all possible combinations of failures that could cause the UAS system to have a safety failure that is defined as "UAV loss of control".

Those combinations included all possible combinations of failures that can occur during three steps of the UAV's mission:

- Take-off
- Flight
- Landing

Human Errors are considered as relevant failures that in combination of other failures can cause the system's critical failure, "UAV loss of control".

4.2. Reliability Data

4.2.1. General

The reliability figures from the lowest elements are propagated to the system's top level.

The reliability figures from two sources have been used:

1. Using Aeronautics field data.
2. Using common reliability data (manufacturers' data, Aeronautics reliability estimation results & BQR data).

4.2.2. Aeronautics' Field Data

- Aeronautics' field data is stored in the Priority system (MRB).
- Every failure is documented.
- Nevertheless, the automated field data collection process lacks some necessary fields of data that should be used during the reliability assessment of the system.

4.2.3. Project Reliability Data Base

- The project reliability data includes Aeronautics' reliability results estimation that is based on Aeronautics' experience and knowledge.
- The project reliability data includes BQR's Reliability Engineering expertise and knowledge base.
- The project reliability data includes manufacturer's reliability data for customized parts.

5. Results

5.1. MTBF calculation

- The MTBF of the UAS system is as following:
  - The MTBF for the UAV - 1107 hours
  - The MTBF for the MCS - 1204 hours
  - The MTBF for the Comm. - 39094 hours
- The MTBF result includes the total summary of all failures that occur in the UAS.
- The MTBF model is a serial model, and thus every failure in the system causes the system's failure.
- The MTBF of the UAS was calculated due to Mil-HDBK-217F-N2 stress parts prediction method, which designed to assist in calculating the MTBF for military applications.
- The MTBF of the UAS was calculated at the AUC (Airborne Un-inhabited Cargo) environment, at 55° degrees, following the instructions in the Mil-HDBK-217F-N2 stress parts prediction method.

5.2. FMECA calculation

- In the FMECA analysis, two single system level failures were defined:
  - Fail, but UAV can return safely.
  - UAV loss of control.
- As it is shown from the results summary table (table 1,2) most of the failures, 99.68%, are summarized to the Severity 4 End Effect, which has no Safety Risk effect.
- There are only 0.32% of total failures that can cause to the "UAV loss of control" End Effect.
- UAV world tends to refer sometimes to MTBCF as MTBL (mean time between losses)

5.3. MTBCF - RBD calculation

- The MTBCF for the entire UAS system, including the UAV, MCS and the Communication modules is: **3683 hours**.
- The MTBCF prediction refers to AUC environment, at 55° degrees.
- The failure rates of components were taken from the MTBF analysis performed by BQR Ltd.

5.4. FTA Calculation

- The hazard analysis of the UAS calculated all the critical combinations of failures that can cause the UAV safety hazard, i.e. “UAV loss of control”.
- The “UAV loss of control” has the following results:

FTA	Failure Rate (per million h)	Probability
UAV loss of control	39.3347	0.00000094

6. Summary and Recommendations

- Due to section 4.2.2, some changes in automatic data collection process should be taken.
- MTBF:
  - The MTBF analysis takes into consideration all components of the entire UAS.
  - For most of the components the Mil-HDBK-217F-N2 was used (Ref. 2.2) as the failure rate prediction model. For the other components, international data bases and experience based data was used.
  - No useful field data was available. Even all failures are documented, some data still missing, which cause this irrelevancy. From this reason a procedure for automated collecting field failures data is recommended. The best way is to use the existing MFG-Pro (ERP system) for collecting and analyzing data, with some modification of the requirements for collected data. A meeting with QA department took place already and a corrective action was planned.
  - Even though, the total field MTBF is available as a mean value, taking into account total number of failures and flight hours, without the breakdown to the components causes. The field total MTBF is lower than the predicted value. This difference will be checked latter with real field data which will be collected due the above recommendation.
- FMECA:
  - As it is shown from the results summary table (see Ref. 5.2) most of the failures, 99.68%, are summarized to the Severity 4 End Effect, which has no Safety Risk effect.
  - In the Aerostar system, there are almost no single failures that can cause to safety hazard, i.e. UAV loss of control.
  - There are only 0.32% of total failures that can cause to the “UAV loss of control” End Effect, which has the Severity 2. But the probability of those failures to happen is very low and acceptable due to Mil-Std-1629A.
- MTBCF:
  - The results show that the entire Aerostar UAS, i.e. the UAV, MCS and the Communication modules, allow continuous work without critical safety failures of the system, though other, not significant failures may occur during the operation of the system.
  - The structure of the Aerostar system includes high-quality components, which allow reducing the risk of critical failures.

- FTA:

- The following failures of the UAV were considered as safety failures, that can lead to “UAV loss of control”:

<u>During Take-off:</u>

- Every deviation from the center line during ground roll as a result of Human error
- Exceptional and unwanted command from the External's pilot box (CBX)
- Foreign Object hit
- Failure in front's wheel servo (stuck in max angle, unwanted angle, etc.)
- Front wheel or one of the main wheels are fracture or disconnected from UAV's body
- Engine's shutdown after take-off (depends on the altitude and the distance from the take-off route lane)
- Serious avionics failure
- Flap's, elevator's servo stuck in extreme angle
- Permanent communication lost

<u>During Landing:</u>

- Human error
- Exceptional and unwanted command from the External's pilot box (CBX)
- Foreign Object hit
- Extra exceptional weather conditions
- Failure in front's wheel servo (stuck in max angle, unwanted angle, etc.)
- Front wheel or one of the central wheels are fracture or disconnected from UAV's body
- Engine's shutdown before approaching to threshold
- No fuel (depending on the landing status)
- Serious avionics failure
- Flap's, elevator's servo stuck in extreme angle
- Permanent communication lost

<u>During flight:</u>

- Engine's shutdown out of safety range for gliding to safe landing
- Avionics failure
- Fire due to exceptional shortage in the main harness or in one of the electric components
- Human error
- Flap's, elevator's servo stuck in extreme angle
- Permanent communication lost

- All failures combinations that can lead to these failures were identified and checked.
- The recommended probability for these critical failures should be 10e-6 for each operational hour, and as it shown from the analysis, the probability for those failures to happen is less than that. Thus, it is within acceptable level.

Recommendations:

Human Errors

In the analysis some Human Errors (HE) were detected as drivers to system failure. These HE were estimated by expert's operators of the UAS. When the field failure analysis system will be completed, the statistics of the HE can be calculated more accurately. One of the options which can help to reduce the statistics is to provide the operators with some data that show the UAV is out of normal operational range, for example "building collision danger". The developers are already implementing a new system which will show the operator the topographic data, such as altitude, and compare it with received data from the UAV sensors to avoid operator HEs. In addition it is recommended to minimize human interference decisions in UAV direct flight control, to reduce such risk.

Battery

It is recommended to put flexible wires for high current wires so they will be less sensitive to vibration or mechanical shock. This is due failures that the wire was straight metal bar and was broken during flight. It is also recommended to double the wire so is one wire will be disconnected (due to open screw) the mission will continue.
It is recommended to double check the battery connection in regular maintenance.

Elevators and ailerons stuck

As a result of some failures, the Elevators and Ailerons might be stuck in critical angle, which complicates and even endanger the normal operation of the UAV. Thus, it is recommended to add mechanism, which will allow the elevators and ailerons always to return to normal angles that will not negatively effect the UAV operation during its flight.

UMAS

The Aerostar airborne UMAS has a very high quality and the design is robust. Nevertheless, critical failure in UMAS may cause to UAV’s loss. Therefore, for our opinion some redundancy or backup components for such critical component should be considered.

Appendix A:

Aerostar Analysis Flow Example

Pilot's Station Failure Example

1. Failure General Description

- Internal Pilot' (IP) station computer has failed.
  - In this case, the Internal Pilot can't see the GMS interface (at the IP bay) Therefore, no data regarding the UAV flight status is shown on the IP station.
- In a case of this failure, a mechanical operation of the UAV is possible, by using the mechanical knobs in the IP station, that allow control over the RTC, which allow to transfer commands to the UAV.
- In a case of a failure in the mechanical knobs, the operation of the UAV can be done by using the Payload Operator (PO) station, where another computer that is operating the GMS software is installed.
- In a case of the failure of the computer in the PO station, a use of mechanical knobs is also possible in order to control the UAV.
- A transfer between the IP and the PO stations is done by a switch, located at the RF drawer.

2. Failure effect on the system

- In case of control lost over the UAV, UAV enters a "return home" (RH) mode.
- Therefore, obtaining a constant communication and thus control over the UAV is important.
- Although, there is no direct safety risk in case of a failure of control loss over the UAV, because the Ground Components have a lot of redundancy, and the UAV enters a RH mode.
- Only if the control can't be regained for a long time (until the fuel of the UAV is finished), a safety hazard can occur.

3. Analysis progression

3.1. MTBF calculation

- First step of the analysis is to perform the Mean Time Between Failures (MTBF) calculation.
- The analysis was made by using the CARE®-MTBF software module.
- The MTBF calculation allows to calculate the MTBF of each part, and relatively the Failure Rate (F.R. = Time Unit/MTBF)
- You can see below the screenshots of the MTBF software module with the relevant components

RefDes	Description	Part Number	Qty
Aero	-	Aeronautics	1
Comm	UAV-MCS communication (Ground + ...	Communication	1
MCS	MCS - Mission Control Station	9.Mission Control Station	1
ExtPilot	External Pilot Stand	6.External Pilot Stand	1
CBX	Flight Box - Instructor	ELC00011-A	1
CBXCable	Cable between Ext.Pilot and the GDT	ELC00050	1
Headset1	Intercom headset PH-4	551169	1
Headset2	Intercom headset PH-4	551169	1
Intercom	Intercom assembly	551165	1
SBX	Flight Box - Trainee	ELC00011-A	1
SBXCable	Cable between Ext.Pilot and the GDT	ELC00050	1
IP	Internal Pilot Stand	IntPilotStand	1
MC	Mission Commander Stand	MisCommStand	1
Other	Other MCS equipment	Other	1
PO	Payload Operator Stand	PayloadStand	1
UAV	Aerostar UAV System	ASTR-xxx	1

Drawing 1 – External Pilot

RefDes	Description	Part Number	Qty
Aero	-	Aeronautics	1
Comm	UAV-MCS communication (Ground + ...	Communication	1
MCS	MCS - Mission Control Station	9.Mission Control Station	1
ExtPilot	External Pilot Stand	6.External Pilot Stand	1
IP	Internal Pilot Stand	IntPilotStand	1
Batt1-2	Battery 12V, 100 Amp/H - RC12-100	550437	2
Headset1	Intercom headset PH-4	551169	1
IP_Other	Internal Pilot's other equipment	IP_Other	1
IndPC1	Industrial Computer	300003	1
KbrdChr1	Keyboard cherry - CHERRY /4100	550335	1
MAG_17	MONITOR MAG 17"LCD LT765S	551138	1
MouseOp1	MOUSE OPTI MICROSOFT	550336	1
PBX	PBX - Pilot box assembly	ELC00011-A	1
PS_Left	P/S 220/27V 36A	550907	1
RFDrawer	MCS RF DRAWER ASSY	AA00007	1
RTC_draw	MCS RTC drawer assy	AA00017	1
UmasCrd1	UMAS CARD AP3 VER-3 ASSEMBLY	ELC00084	1
MC	Mission Commander Stand	MisCommStand	1
Other	Other MCS equipment	Other	1
PO	Payload Operator Stand	PayloadStand	1
UAV	Aerostar UAV System	ASTR-xxx	1

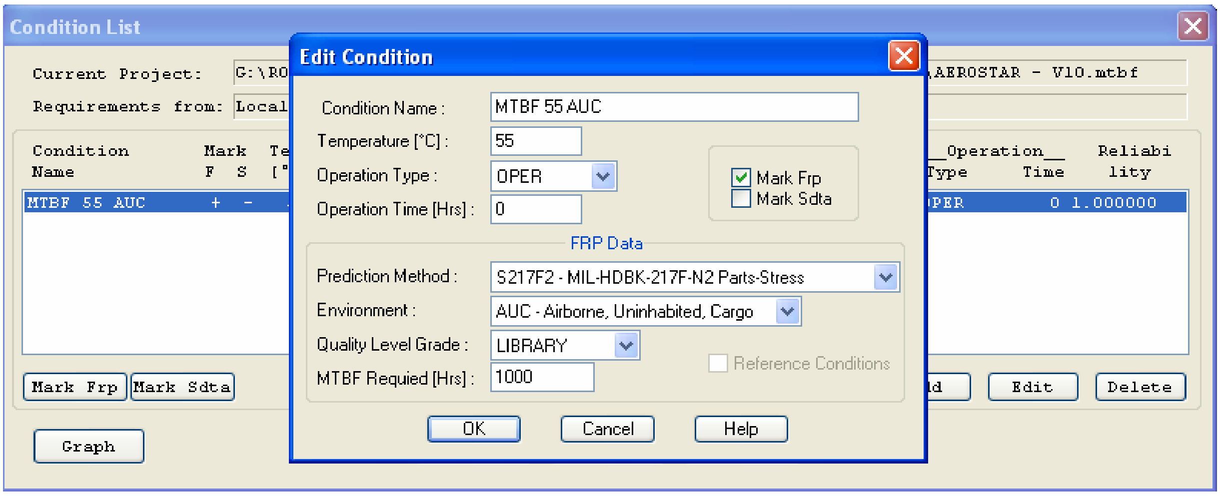
Drawing 2 – Internal Pilot

RefDes	Description	Part Number	Qty
Aero	-	Aeronautics	1
Comm	UAV-MCS communication (Ground + ...	Communication	1
MCS	MCS - Mission Control Station	9.Mission Control Station	1
ExtPilot	External Pilot Stand	6.External Pilot Stand	1
IP	Internal Pilot Stand	IntPilotStand	1
MC	Mission Commander Stand	MisCommStand	1
Intercom	Intercom central unit	551165	1
IntrMic	Intercom microphone - 38999/20WD...	551167	1
Mon14	14" Monitor	551014	1
UPS	UPS - NET-PRO 2000	551139	1
VCR1	VCR NTSC 2-head - Toshiba - V-E29	551200	1
VCR2	VCR NTSC 2-head - Toshiba - V-E29	551200	1
Other	Other MCS equipment	Other	1
PO	Payload Operator Stand	PayloadStand	1
UAV	Aerostar UAV System	ASTR-xxx	1

Drawing 3 – Mission Commander

RefDes	Description	Part Number	Catalo...	Qty
Aero	-	Aeronautics	---	1
Comm	UAV-MCS communication (Ground + Air)	Communication	-	1
MCS	MCS - Mission Control Station	9.Mission Control Station	AA00006	1
ExtPilot	External Pilot Stand	6.External Pilot Stand	-	1
IP	Internal Pilot Stand	IntPilotStand	-	1
MC	Mission Commander Stand	MisCommStand	-	1
Other	Other MCS equipment	Other	-	1
PO	Payload Operator Stand	PayloadStand	-	1
Batt3-4	Battery 12V, 100 Amp/H - RC12-100	550437	RC12-100	2
Headset2	Intercom headset PH-4	551169	-	1
IndPC2	Industrial Computer	300003	-	1
IndPC3	Industrial Computer	300003	-	1
Joystick	Logitech wingman extreme dig 3D	551095	-	1
KbrdChr2	Keyboard cherry - CHERRY /4100	550335	-	1
MonAssy	MCS A-RACK 17" monitor assy	AA00008	-	1
Mon_14	14" Monitor - PVM14N5E	551014	PVM14N5E	1
MouseOp2	MOUSE OPTI MICROSOFT	550336	-	1
PO_Other	Payload Operator other equipment	PO_Other	-	1
PS_Right	P/S 220/27V 36A	550907	-	1
RTC_draw	MCS RTC drawer assy	AA00017	-	1
TchScrAs	TOUCHSCREEN 10.4" ASSY	AA00048-A	-	1
UmasCrd2	UMAS CARD AP3 VER-3 ASSEMBLY	ELC00084	-	1
UAV	Aerostar UAV System	ASTR-xxx	-	1

Drawing 4 – Payload Operator

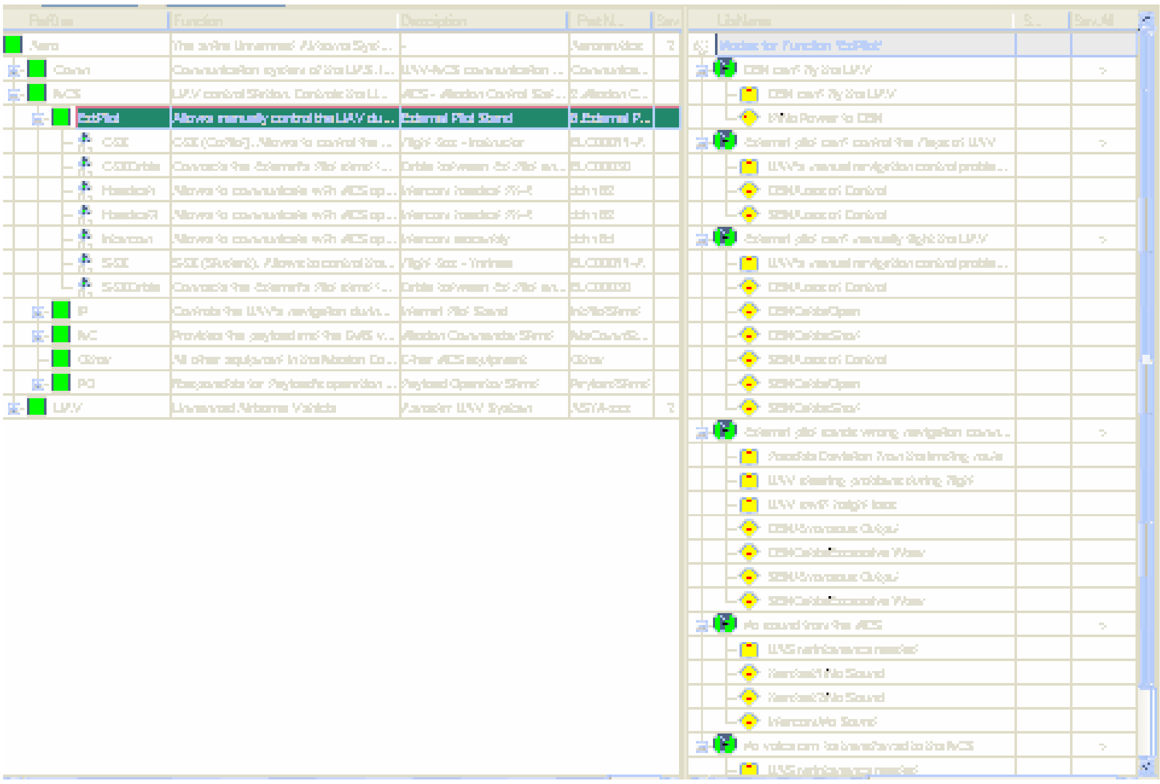


Drawing 5 – Calculation Condition

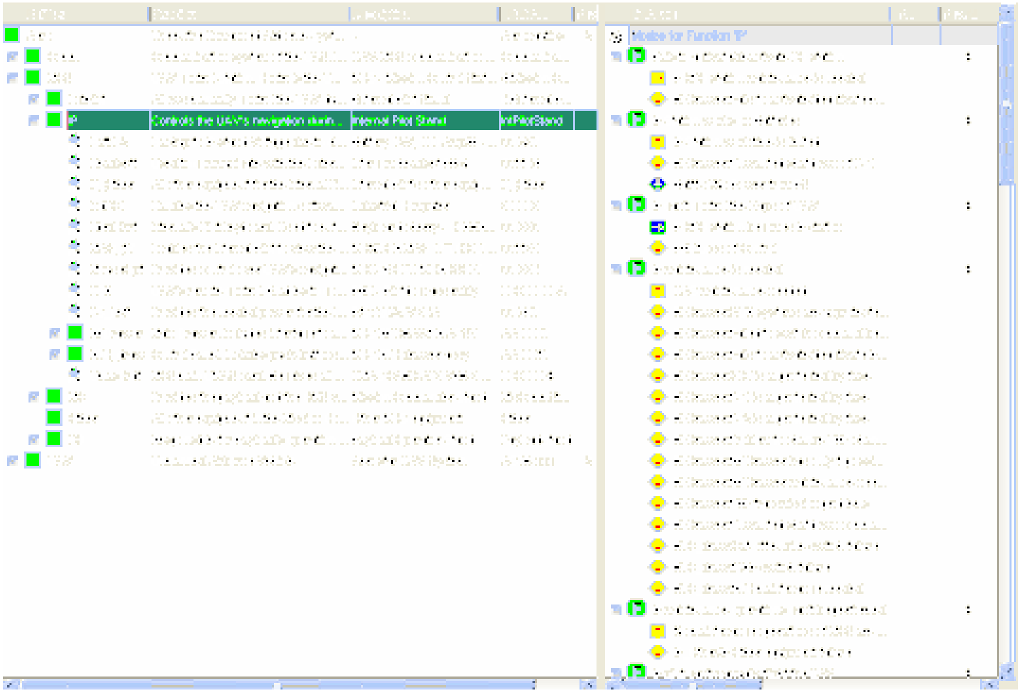
- For every relevant component MTBF was calculated.
- This MTBF was transferred to our Core Data Base, for latter use by other modules, such as RBD (MTBCF calculation) and the FMECA modules.

3.2. FMECA Calculation

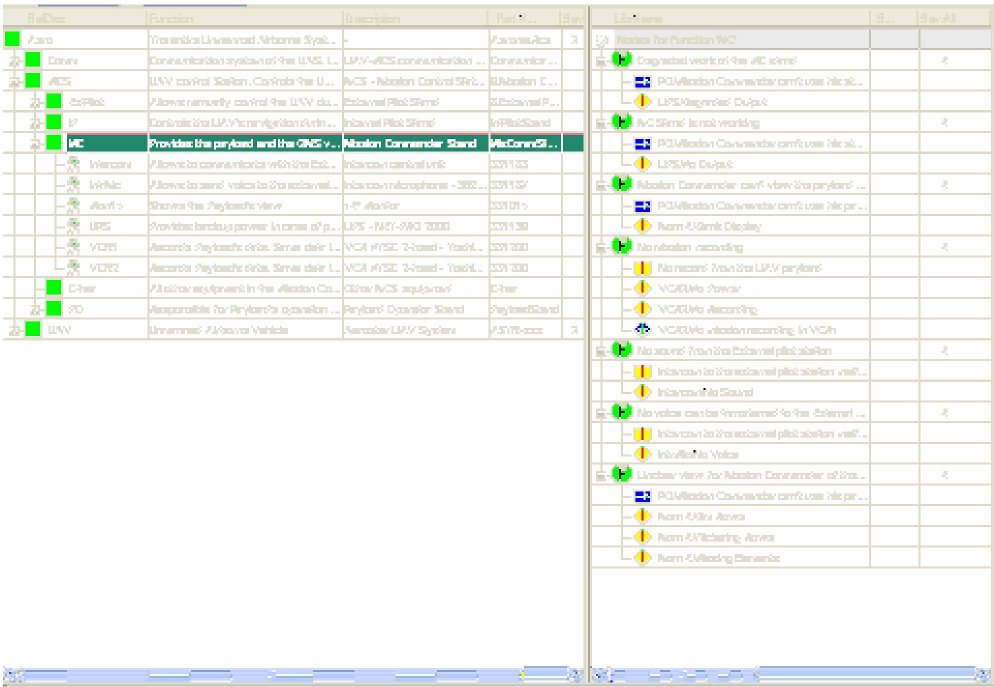
- After creating the MTBF calculation, the project's data was transferred to the CARE®-FMECA software module.
- In the FMECA software module, an analysis of the Failure Modes Effects and Criticality Analysis was made.
- Every component was analyzed for its possible failures.
- Every failure was analyzed for its effects on the entire system.
- After that, a criticality matrix of all the failure modes with their severity and probability was created.
- You can see below the screenshots of the FMECA software module with the relevant components.



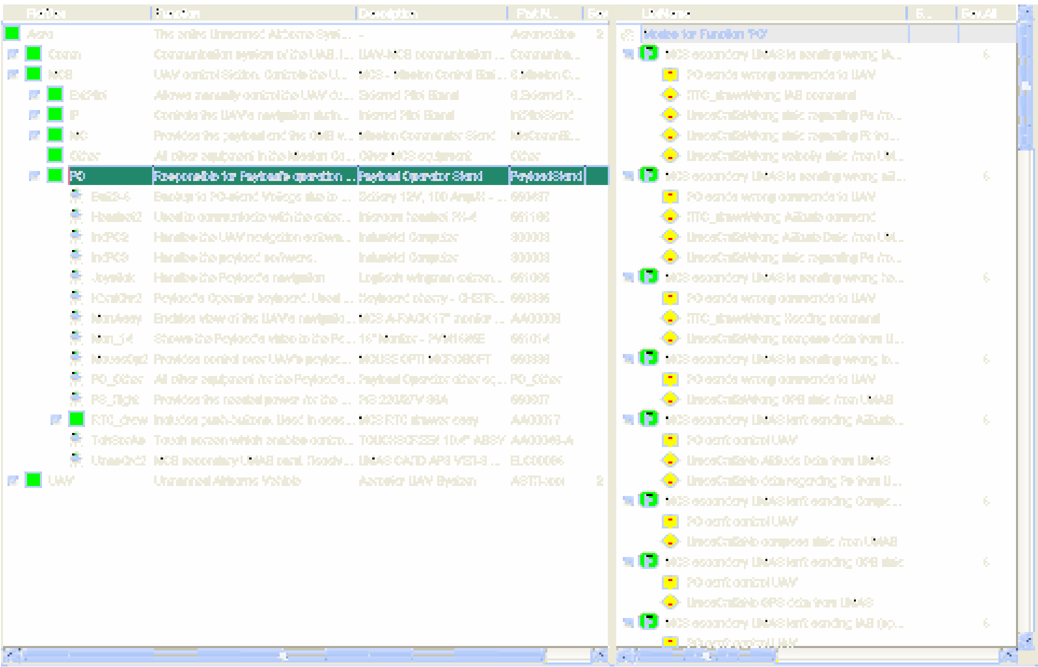
Drawing 6 – FMECA for External Pilot



Drawing 7 – FMECA for Internal Pilot

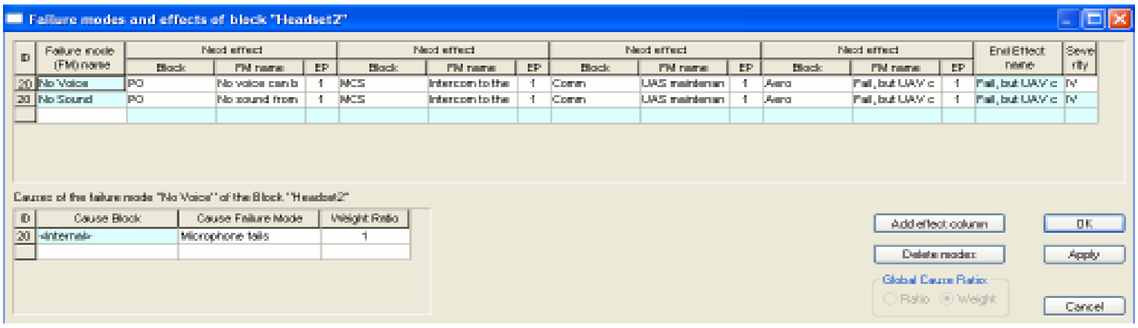


Drawing 8 – FMECA for Mission Commander



Drawing 9 – FMECA for Payload Operator

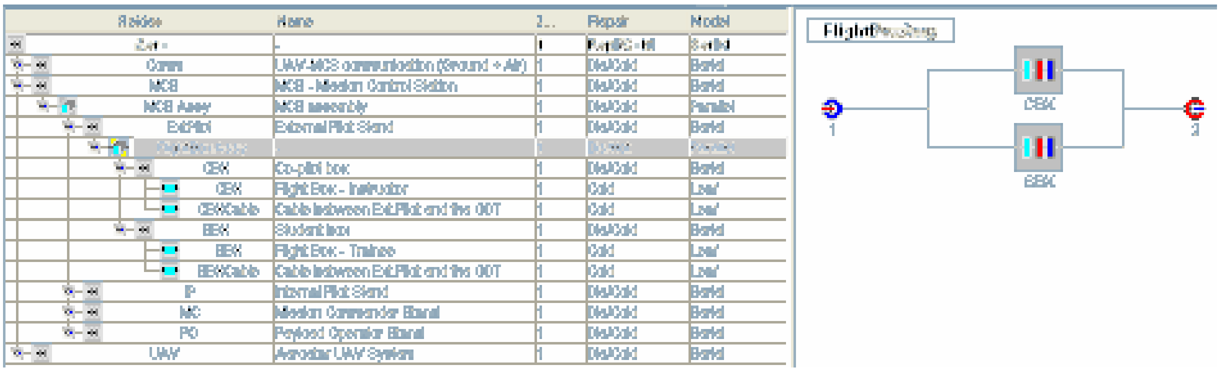
- You can see for every relevant component on the right side of the screen, for every component its failure modes. The failure modes are marked as F.
- Every failure mode has the cause, i.e. the reason why the failure mode occurred. The cause is marked as a down-headed arrow , or as .
- Every failure is propagated up to the system level.
- This way, a trace of every single failure from the reason it happens, and up to the system level, where this failure's effect on the entire system, is shown.



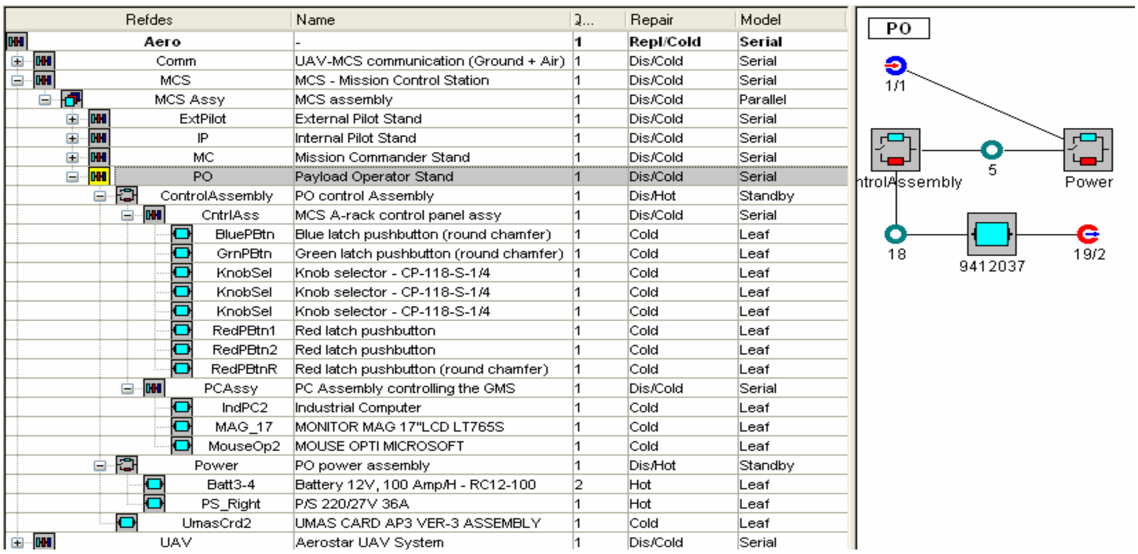
Drawing 10 – FMECA example for the entire trace of Headset failure

3.3. *Reliability* Model *by using CARE®*-RBD

- Creating the MTBF model was made by using a serial model, where every failure was considered as a failure that fails the system.
- In order to create an accurate model for the UAS, a Reliability Block Diagram (CARE®-RBD) software was used.
- In this software, not only serial model can be used. Therefore, all redundancies in the system could be taken under consideration.
- You can see below the screenshots of the FMECA software module with the relevant components.

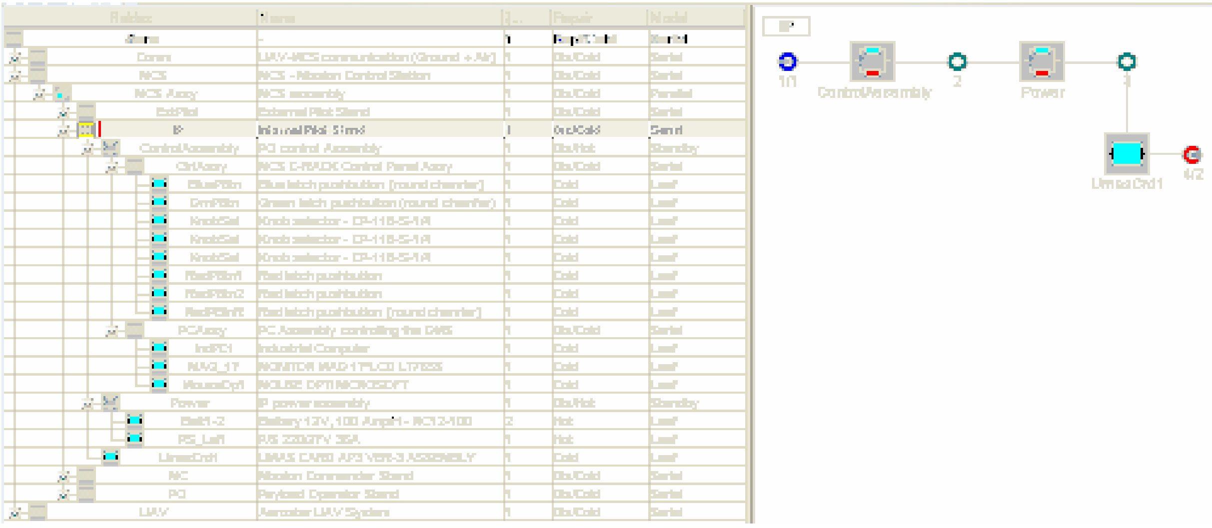


Drawing 11 – RBD for External Pilot



Refdes	Name	Q...	Repair	Model
Aero	-	**1**	**Repl/Cold**	**Serial**
Comm	UAV-MCS communication (Ground + Air)	1	Dis/Cold	Serial
MCS	MCS - Mission Control Station	1	Dis/Cold	Serial
MCS Assy	MCS assembly	1	Dis/Cold	Parallel
ExtPilot	External Pilot Stand	1	Dis/Cold	Serial
IP	Internal Pilot Stand	1	Dis/Cold	Serial
MC	Mission Commander Stand	1	Dis/Cold	Serial
PO	Payload Operator Stand	1	Dis/Cold	Serial
ControlAssembly	PO control Assembly	1	Dis/Hot	Standby
CntrlAss	MCS A-rack control panel assy	1	Dis/Cold	Serial
BluePBtn	Blue latch pushbutton (round chamfer)	1	Cold	Leaf
GrnPBtn	Green latch pushbutton (round chamfer)	1	Cold	Leaf
KnobSel	Knob selector - CP-118-S-1/4	1	Cold	Leaf
KnobSel	Knob selector - CP-118-S-1/4	1	Cold	Leaf
KnobSel	Knob selector - CP-118-S-1/4	1	Cold	Leaf
RedPBtn1	Red latch pushbutton	1	Cold	Leaf
RedPBtn2	Red latch pushbutton	1	Cold	Leaf
RedPBtnR	Red latch pushbutton (round chamfer)	1	Cold	Leaf
PCAssy	PC Assembly controlling the GMS	1	Dis/Cold	Serial
IndPC2	Industrial Computer	1	Cold	Leaf
MAG_17	MONITOR MAG 17"LCD LT765S	1	Cold	Leaf
MouseOp2	MOUSE OPTI MICROSOFT	1	Cold	Leaf
Power	PO power assembly	1	Dis/Hot	Standby
Batt3-4	Battery 12V, 100 Amp/H - RC12-100	2	Hot	Leaf
PS_Right	P/S 220/27V 36A	1	Hot	Leaf
UmasCrd2	UMAS CARD AP3 VER-3 ASSEMBLY	1	Cold	Leaf
UAV	Aerostar UAV System	1	Dis/Cold	Serial

Drawing 12 – RBD for Payload Operator



Drawing 13 – RBD for Internal Pilot

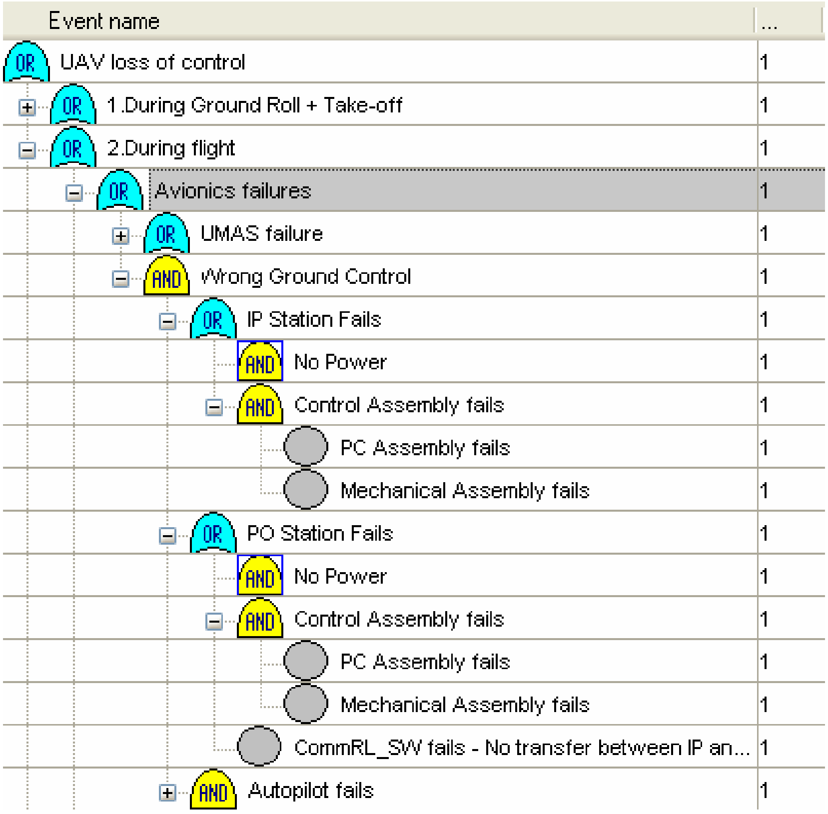
- It can be seen that only critical components that are necessary for the normal UAS operation were taken under consideration.
- The redundancies of the system can be shown here, such as Control Assembly of every station:
    - For example in the IP station, there are 2 control assemblies that can control the UAV as we described in our Example Description:
        - The PC assembly
        - The mechanical knobs assembly
    - Therefore the connecting gate of those 2 control assemblies is a Stand-by model. i.e. only when the main (PC) control assembly fails, the secondary (Mechanical) control assembly goes into operation. And only if both of those assemblies are not working, then there is a problem to control the UAV from the IP station.
- Therefore the MTBCF tree structure and hierarchy is different than the MTBF product tree.
- The following redundant types were used:
    -  - Parallel – i.e. only when all the sub-blocks of this block fail, the block fails
    -  - Stand-by – i.e. only the main sub-block operating. When the main sub-

block fails, the secondary sub-block starts to work. And only when both sub-blocks fail, the block fails.

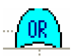
- - Serial – i.e. every failure in any of the sub-blocks, cause the block's failure.
- - Simple – i.e. this block is the simple "leaf".

3.4. Fault Tree Analysis (FTA)

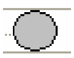
- After creating the FMECA model, a creation of the Fault Tree is possible.
- The FTA model was built by using the CARE®-FTA software module.
- In the FTA all the failures combinations that are leading to the safety fault were examined.
- Below you can see the relevant screenshots from the FTA module:



Drawing 14 – FTA for wrong ground control

- Different connections can be viewed in the FTA diagram.
- These connections show the different logical conditions that have to happen, in order for these failures to effect the system.
- 

 - OR Gate. i.e. every failure in one of the sub-events will trigger this failure
- 

 - AND Gate. i.e. only when all sub-events will fail this failure will be triggered
-  - End Cause event. i.e. the cause for the failure.