AIRCRAFT CANON TARGETING SYSTEM (ACTS) RELIABILTIY ANALYSIS

Introduction

The Aircraft Cannon Targeting Systems (ACTS) is a critical component in combat aircraft comprising of 11 subsystems initially configured in series (Mod 1). Its reliability directly impacts mission success and crew safety during high-stake operations. To improve reliability, two modifications are proposed: Mod 2 adds a second servo controller in full active redundancy, while Mod 3 incorporates it in standby redundancy.

This report calculates subsystem and system reliabilities, evaluates an enhanced servo controller, conducts a fault tree analysis (FTA) for Mod 2, and compares redundancy versus component improvement strategies, all contextualized for combat aircraft operations. The table below shows the components on the system.

Component	Code	Failure rate per million flying hours	Failure rate per hour (λ)
Power Supply	PS	207.95	2.0795E-04
HUD Interface Unit	HIU	93.37	9.3370E-05
Servo Controller	SC	531.3	5.3130E-04
Elevation Surface Actuator	ESA	57.54	5.7540E-05
Azimuth Servo Actuator	ASA	125.35	1.2535E-04
Ammunition Feed System	AFS	82.98	8.2980E-05
ECU	ECU	11.14	1.1140E-05
Recoil System	RS	203.33	2.0333E-04
Temperature Sensor	TS	77.55	7.7550E-05
Airspeed Sensor	AS	90.59	9.0590E-05
Ballistic Load Sensor	BLS	134.56	1.3456E-04

Table 1- Components on the ACT System with respective failure rates.

In Mod 1, all 11 components are configured in a series arrangement, as depicted in Figure 1. In Mod 2, a supplementary servo controller is integrated in parallel with the existing servo controller to provide full active redundancy, enhancing system reliability, as shown in Figure 1. In Mod 3, an additional servo controller is incorporated in parallel with the existing servo controller, but configured for standby redundancy, ensuring backup availability in case of failure, as illustrated in Figure 1.

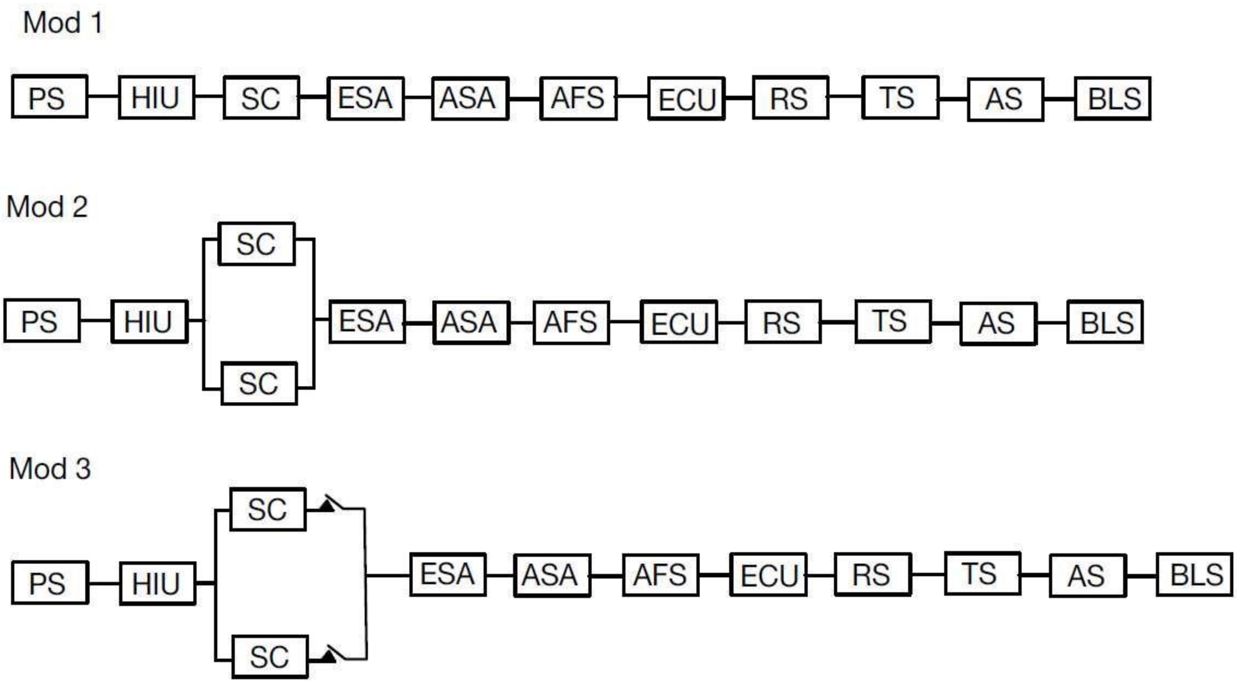

Figure 1: Configurations of all three models.

Question 1: Unreliability of Servo Controller and Reliability of Parallel Subsystems

A. Unreliability of Servo Controller (Q_{D1}) at 400 Flying Hours

Unreliability Q_{D1} measures the probability of failure, derived from reliability R_{D1}.

Formula Used:

$Q_{D1} = 1 - R_{D1}$ **Equation 1**

$R_{D1} = e^{-\lambda t}$ (exponential reliability model assuming constant failure rate) **Equation 2**

Data Given:

$\lambda_{SC} = 531.3\ per\ million\ flying\ hours = \frac{531.3}{1{,}000{,}000}$ = 5.3130 $x\ 10^{-4}$

Operating hours (t) = 400 Hours

Solution:

Firstly, compute the exponent:

$$\lambda t = (5.3130\ x\ 10^{-4})\ x\ 400 = 0.21252$$

Then:

$$R_{D1} = e^{-0.21252} = 0.808544 \text{ (using } e^{-x} \text{ from calculator)}$$

$$Q_{D1} = 1 - 0.808544 = 0.191458547$$

Results:

$Q_{D1} =$ 0.191456 (rounded off to 5 decimal places)

Explanation:

The exponent λt represents the expected number of failures over 400 hours, and $e^{-\lambda t}$ gives the survival probability, with Q_{D1} as its competent.

Equation 1 represents the probability of failure over a given time, derived as the complement of reliability, ensuring the total probability (reliability + unreliability) equals 1.

Equation 2 models the reliability of component assuming an exponential failure distribution, where λ is a constant failure rate (failures per hour) and t is the operating time. The exponential model is appropriate for electronic and mechanical systems with a constant hazard rate.

B. Reliability of Parallel Servo Controller Subsystems (R_{COMP}) in Mod 2 at 400 Flying Hours

For full active redundancy, both servo controllers operate simultaneously, and the subsystem fails only if both fail.

Formula Used:

$R_{Comp} = 1 - (1 - R_{D1})^n$ **Equation 3**

Data Given:

R_{D1} =0.808544

n = 2

Solution:

$R_{Comp} = 1 - (1 - 0.808544)^2$

$R_{Comp} = 1 - 0.0366554$

Results:

$R_{Comp} = 0.963345$

Explanation:

Squaring $1 - R_{D1}$accounts for the joint probability of both independent failures and subtracting from 1 gives the probability that at least one unit survives.

Equation 3 calculates the reliability of a system with n identical components in parallel, where all must fail for the system to fail. For $n = 2$, it reflects full active redundancy, where both units operate simultaneously, and the system survives as long as at least one-unit functions.

Question 2: Systems Reliability (RS) for Mod 1, Mod 2, and Mod 3 at 10 and 400 Hours

A. Mod 1 (Series System) at 10 and 400 Flying Hours

For this, the reliability of each components was calculated using **Equation 2** at both 10 and 400 flying hours.

The calculations in this section helps to determine the overall probability of the system functioning without failure, a key metric for assessing the baseline performance of the targeting system in short and long combat missions.

		Reliability	
Component	λ	t=10	t=400
Power Supply	2.0795E-04	0.997922661	0.920185499
HUD Interface Unit	9.3370E-05	0.999066736	0.963340834
Servo Controller	5.3130E-04	0.994701089	0.808544145
Elevation Servo Actuator	5.7540E-05	0.999424766	0.977246848
Azimuth Servo Actuator	1.2535E-04	0.998747285	0.951096262
Ammunition Feed system	8.2980E-05	0.999170544	0.967352810
ECU	1.1140E-05	0.999888606	0.995553913
Recoil System	2.0333E-04	0.997968766	0.921887574
Temperature Sensor	7.7550E-05	0.999224801	0.969456184
Airspeed Sensor	9.0590E-05	0.99909451	0.964412665
Ballistic Load sensor	1.3456E-04	0.998655305	0.947598869

Table 2- Failure rates and the reliability of components in Mod 1

Given that all components are arranged in series, **Equation 2** was utilized to calculate the overall reliability of the system in Mod 1.

$$R_s = product\ of\ the\ reliability\ of\ each\ individual\ component$$ **Equation 4**

t(hours)	R_s
10	0.983973218
400	0.523999788

Table 3- Reliabilities of the system in Mod 1 at 10 and 400 flying hours

B. Reliability of the ACTS in Mod 2 at 10 and 400 Flying Hours

This part calculates the systems reliability R_s of the ACTS in Mod 2, which includes two servo controllers in full active redundancy, at 10 and 400 flying hours. This evaluates how redundancy enhances overall system performance compared to Mod 1, critical for assessing its viability in combat aircraft over varying mission durations.

Equation 3 as outlined in question 1B was used to calculate the redundancy of the subsystem for both 10 and 400 flying hours. The reliability of each component was calculated using **Equation 2** at both 10 and 400 flying hours except for the two parallel servo controllers that are in full active redundancy. As a result, all components except the controller servo subsystem maintained the same reliability values as those calculated in Mod 1.

	$t = 10$	$t = 400$
λ	0.0053134	0.0053134
R_{D1}	0.994701	0.808544
R_{Comp}	0.999972	0.963345

Table 4- Reliability of the two servo controllers in full active redundancy

Equation 4 was applied to calculate the overall reliability of the system for both 10 and 400 flying hours.

t(hours)	R_s
10	0.98972
400	0.61345

Table 5- Reliabilities of the system in Mod 2 at 10 and 400 flying hours

C. Reliability of the ACTS in Mod 3 at 10 and 400 Flying Hours

This part calculates the systems reliability R_s of the ACTS in Mod 3, featuring two servo controllers in stand by redundancy at 10 and 400 flying hours. This assess the effectiveness of standby redundancy in enhancing reliability, providing insight into its suitability for combat aircraft mission of different lengths.

Formula Used:

The reliability of each component was calculated using **Equation 2** at both 10 and 400 flying hours except for the two parallel servo controllers that are in full active redundancy.

$R_{AB} = e^{-\lambda t} + \lambda t e^{-\lambda t}$ **Equation 5**

Data Given:

$\lambda = 531.3\ per\ million\ flying\ hours = \frac{531.3}{1,000,000}$ = 5.313 $x\ 10^{-4}$ (for servo controller)

Operating hours (t) = 10 and 400 Hours

Solution:

t	Computation	R_{AB}
10	0.994697 + 0.005286	0.99998
400	0.808660 + 0.17165	0.98031

Table 6- Reliability of the two servo controllers in full active redundancy

Equation 4 was applied to calculate the overall reliability of the system for both 10 and 400 flying hours.

t(hours)	R_s
10	0.98973
400	0.62367

Table 7- Reliability of the system in Mod 3 at 10 and 400 flying hours

Explanation:

Equation 5 models standby redundancy, where a backup unit activates upon the primary units failure. The first term ($e^{-\lambda t}$) is the reliability of the primary unit, and the second term ($\lambda t e^{-\lambda t}$) accounts for the probability if the backup unit operating successfully after the primary fails, assuming perfect switching.

The reliability 0.98973 at 10-hours and 0.62367 at 400-hours indicates a slight edge over Mod 2, particularly at longer durations due to standby redundancy's higher effectiveness when one unit fails. The 62.367% success probability at 400-hours suggests robust performance, though it remains constrained by non-redundant components.

D. WHY MTBF (MEAN TIME BETWEEN FAILURE) Cannot Be Converted for Mod 2

Solution:

MTBF (mean time between failure) cannot be calculated as a single value because the inclusion of two servo controllers in full active redundancy results in non-constant failure rate over time. Initially, both units operate, and the system fails only if both fail, deviating from the exponential model.

The dynamic failure rate in Mod 2, due to redundancy means the systems reliability does not follow a simple ($e^{-\lambda t}$) decay. This complexity precludes a meaningful MTBF (mean time between failure), as it assumes a constant hazard rate, making time-independent metrics inappropriate for redundancy enhanced systems in combat scenarios.

Question 3: Impact of 80% MTBF Improvement on Mod 1

This part evaluates whether improving the servo controller's MTBF by 80% sufficiently enhances Mod 1's reliability to eliminate the need for redundant element in Mod 2 or Mod 3, considering both numerical results and the drawbacks of redundancy. This is key to determining the best reliability strategy for combat aircraft at 10 and 400 hours

.

Formula Used:

$MTBF_1 = \frac{1}{\lambda}$ (Original MTBF) **Equation 6**

$MTBF_2 = MTBF_1\ x\ 1.8$ (Improved MTBF) **Equation 7**

Data Given:

Original $\lambda = 5.3130\ x\ 10^{-4}$ per hour

Operating hours $t = 10\ and\ 400$

Solution:

$$MTBF_1 = \frac{1}{5.3130\ x\ 10^{-4}} = 1882.175795\ Hours$$

$$MTBF_2 = 1882.175795\ x\ 1.8 = 3387.916431\ Hours$$

New failure rate $\lambda_2 = \frac{1}{3387.916431} = 2.95167 \, x \, 10^{-4}$ per hour

The reliabilities of the system at 10 and 400 hours with the improved MTBF for the servo controller, was calculated using **Equation 4**

t(hours)	R_s
10	0.98623
400	0.56389

Table 8- Reliability of the system with improved servo controller MTBF

	Old MOD 1	Improved MOD 1	MOD 2	MOD 3
t=10	0.98397	0.98623	0.98972	0.98973
t=400	0.52399	0.56389	0.61345	0.62367

Table 9- Comparison Table for all Mods at both 10 and 400 flying hours

Explanation:

Equation 6 applies to systems with a constant failure rate, providing an average time between failure, valid only for exponential reliability models. This issue arises because Mod 2's redundancy (via $R_{Comp} = 1 - (1 - R_{D1})^2$) alters the failure rate dynamically, invalidating the constant rate assumption.

Equation 7 reflects enhanced component durability with the MTBF increasing by 1.8 times due to an 80% improvement increase.

The improved Mod 1's reliability increase narrows the gap with Mod 2/3. Drawbacks like increased cost, weight, and complexity (e.g., 10-15 kg added weight affecting agility) must be weighed against this gain, indicating the improvement is insufficient to eliminate redundancy in combat scenarios where safety is paramount.

Question 4: Fault Tree Analysis (FTA) for Mod 2

This part constructs a Fault Tree Analysis (FTA) for Mod 2 to identify all possible failure paths leading to the ACTS System failure, using logical gates to represent the series redundant configurations. This is essential for diagnosing and mitigating risks in combat aircraft's targeting system.

Explanation:

The FTA maps all failure paths, showing that the system fails only if both servo controllers and all other components fail. This structure aids in pinpointing critical failure modes such as the servo controller for combat aircraft reliability enhancement.

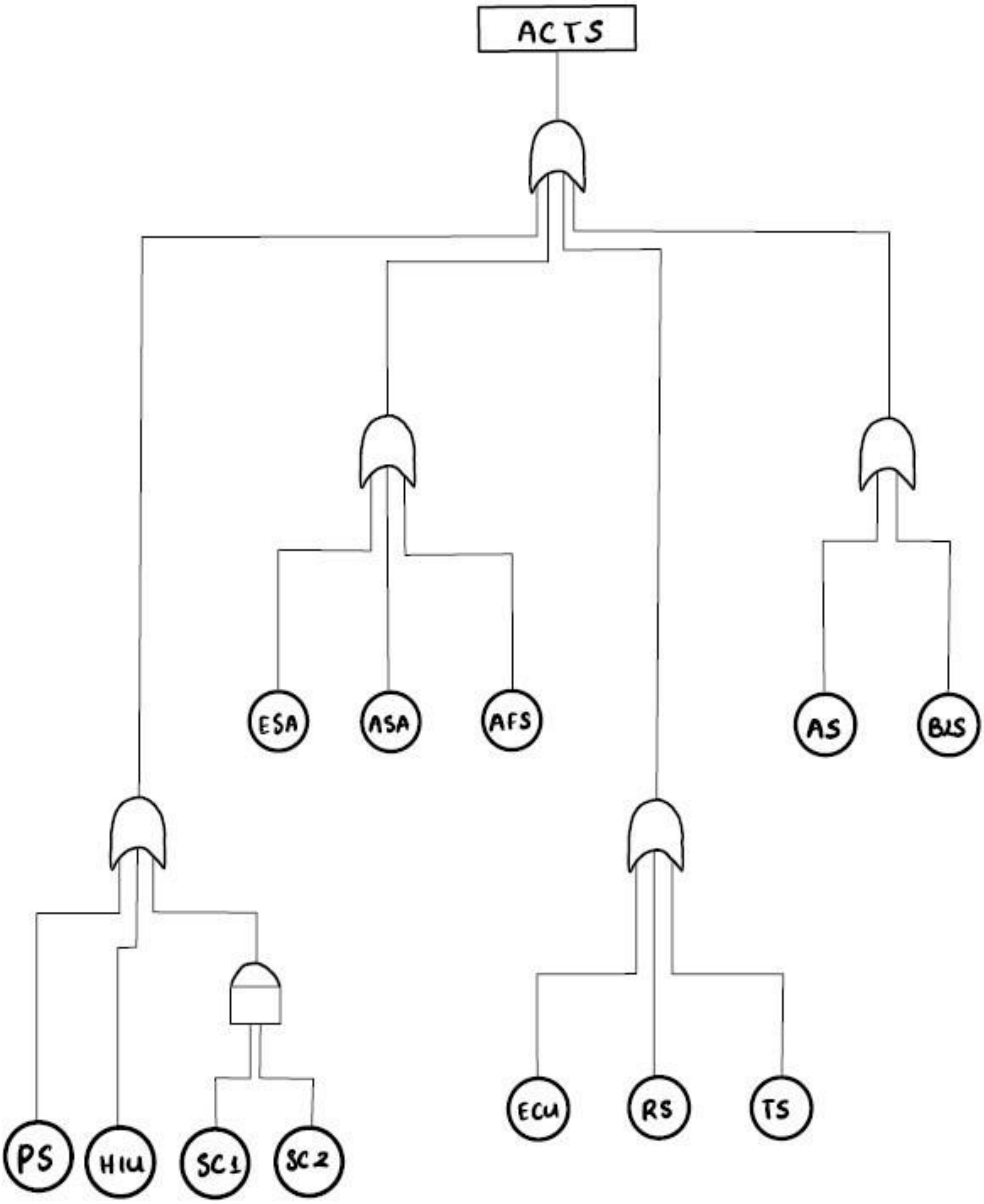

Figure 2 - FTA diagram on Mod 2.

Question 5: Discussion of Redundancy vs. Mature Product in Combat Aircraft Context

This part discusses the advantages and disadvantages of incorporating redundant elements (Mod 2 and Mod 3) versus developing a mature product with improved MTBF (enhanced Mod 1), weighing these options against the operational constraints of combat aircraft. This is crucial for deciding the best reliability strategy for missions lasting 10 to 400 hours, where failure could jeopardize mission success or safety.

Formula Used:

Reliability equations and MTBF (Equation 6) are referenced as explained above, underpinning the reliability comparisons.

Data Given:

Combat aircraft constraints: weight (e.g., F-35's 31,800 pounds limit), cost (e.g., 80 Million Dollars per unit)

Discussion:

The choice between redundancy and mature product hinges on reliability, safety, cost, and operational continuity in combat aircraft. Redundancy in Mod 2 ($R_{Comp} = 1 - (1 - R_{D1})^2$) and Mod 3 ($R_{AB} = e^{-\lambda t} + \lambda t e^{-\lambda t}$) boosts reliability to 0.61345 and 0.62367 at 400 hours, offering a 0.05-0.06 advantage over improved Mod 1's 0.56389. This is vital in 400-hour missions (e.g., strategic bombing), where a failure could miss a target, exposing the aircraft to counterattacks.

The backup ensures continuity, critical in combat zones without repair options, though it adds 10-15 kg (affecting agility against fighters) and doubles maintenance costs, straining budgets for large fleets.

The mature product, with MTBF increased to 3387.916431 $Hours$ ($MTBF_2 = MTBF_1\ x\ 1.8$) raises Mod 1 reliability to 00.98623 (10 hours), nearing Mod 2/3's 0.98972/0.98973, suitable for short missions where weight savings enhance manoeuvrability. However, its lack of backup risks total failure at 400 hours, unacceptable in prolonged engagements. The upfront Research & Development cost for a mature product is high but eliminates recurring redundancy expenses, favouring cost-sensitive operations.

For combat aircraft, 400-hour missions prioritize safety, making Mod 3's 0.62367 reliability and standby redundancy optimal, despite weight and cost, given the life-or-death stakes. Short missions (10 hours) could leverage improved Mod 1 if agility outweighs the 0.0035 reliability gap, but redundancy's safety net prevails for most scenarios.

Explanation:

The discussion balances numerical reliability gains with combat-specific constraints, showing redundancy's edge in long missions despite drawbacks, while the mature product suits shorter, cost-driven operations, aligning with the ACT system's combat role.

CONCLUSION

The analysis shows that an 80% MTBF improvement enhances Mod 1 reliability but does not eliminate the need for redundancy, especially for 400-hour mission where 0.05-0.06 gap is critical. Mod 2 and Mod 3 offer superior reliability at higher cost and weight, aligning with combat aircraft needs. The mature product suits short missions and budget constraints, but redundancy is optimal for extended engagements.

REFERENCES

1. Ibm. (n.d.). What is MTBF? Retrieved from https://www.ibm.com/topics/mtbf
2. Orscheln Products. (n.d.). Redundant Aircraft Systems. Retrieved from https://orschelnproducts.com/redundant-aircraft-systems/