An Economic Analysis of False Alarms and No Fault Found Events in Air Vehicles

Mustafa İLARSLAN, Ph.D.,
Ankara, Turkey
milarslan@yahoo.com

Louis Y. Ungar,President,
A.T.E. Solutions, Inc.
400 Continental Blvd., 6th Floor
El Segundo, CA 90245
LouisUngar@ieee.org

Kenan İLARSLAN, Ph.D.
Afyon Kocatepe
University
Afyonkarahisar, Turkey
ilarslan@aku.edu.tr

Abstract—**False Alarms (FAs) that occur in a fielded system and No Fault Found (NFF) events that are discovered after line replaceable units (LRUs) have been returned to repair are costly situations whose full impact is difficult to put into monetary terms. For that reason, pragmatic economic models of NFFs are difficult to develop. In this paper, we deal with the problem of having to differentiate between NFFs of good units under test (UUTs) and of faulty UUTs. While we cannot tell which UUT is good and which is faulty, we can determine using probabilities what percentage of the NFFs are faulty and what percentage are good. Based on these probabilities, we can evaluate various strategies. Assigning cost factors that are knowable, such as the cost of testing a UUT, the cost we incur for good UUTs vs. costs we incur for faulty UUTs and various test and repair costs, we can calculate the performance of various strategies and assumptions. In this paper, we formulate three strategies: 1) We assume all NFF UUTs are good and are willing to endure the cost of bad actors (i.e. faulty UUTs) sent back to the aircraft. 2) We assume all NFF UUTs are faulty and we environmentally stress all NFF UUTs, hoping to fix some and avoid bad actors. 3) We rely on the technician to reasonably select some NFF UUTs and perform appropriate repair.**

We formulate each of these strategies for a case when NFF is 70%. The formulation is similar with any NFF distribution, but the coefficients in each formula will be different. With proper cost data, we can actually decide which strategy works best. We conclude by tabulating the formulas and calculate NFF costs for an example situation. The numbers we picked for this example may be appropriate for some operations, but not for others. As a follow-up to this paper we would like to validate the model with real data, which may be available in some military and commercial avionics maintenance departments.

Keywords—False Alarms, No Fault Found, Test economics, Cost model

I. BACKGROUND

The test profession is concerned with test methods that find faults. An important caveat is that often faults are found when the system is fault free. We call such occurrences false alarms (FAs), but it is often not possible to distinguish between a real and a false call for maintenance. As a result of FAs, a number of line replaceable units (LRUs), also called units under test (UUTs) that are removed from an aircraft appear to the automatic test equipment (ATE) in the repair facility as a No Fault Found (NFF) event. Many, probably most of the UUTs experiencing NFF are fault free and therefore incur a cost that should be minimized. Other UUTs labeled NFF are faulty but cannot be recognized as such.

We concern ourselves in this paper with the economic impact of NFFs and the cost we incur when we assume incorrectly that a good UUT is faulty or when we assume a faulty UUT is good.

In an attempt to cover nearly all faults, tests inherently fall prey to False Positive (FP) indications. While the majority of faulty units fail tests, a condition we call True Positive (TP), and the majority of good units pass tests, a condition we call True Negative (TN), some faulty units escape and pass the test and we call that condition False Negative (FN). The last condition, namely when a good unit fails the test is FP, and when it causes removal of LRUs that are not faulty, we call this situation false alarms (FAs). When one or more LRUs are removed in response to FAs, the repair facility ATE will render them as NFF. Additionally, other causes of NFF are possible, including the removal of the wrong LRU, removal of more than one LRU, intermittent failures and ATE test escapes. For all these reasons, NFFs are typically upwards of 70% of the LRUs removed from the aircraft when tested by the repair facility ATE.

Economic analyses into the cost of FAs and NFFs have been included as a part of articles and texts dealing with the NFF phenomenon. In [1] various strategies were compared from a cost perspective. In [2] a list of FA and NFF cost factors were included. In [3] there was extensive discussion on mitigating these costs without specifically calculating them. In [4] there is extensive research about the root cause of NFF, but few specifics on economic analysis. A framework to NFF cost drivers is discussed in [5]. Economic information can also be derived from [6]. While all these sources and others provide some gage for the economic burden posed by NFFs, we would like to be able to plug numbers into formulas or Excel spreadsheet that will give us a precise cost impact of NFF events.

The difficulties of economic analyses center around the highly probabilistic nature of NFFs. When faced with NFF, our cost will be impacted greatly by:

1. Whether we assume that NFF events represent good UUTs or that they represent faulty UUTs or both.
2. Whether the cost of guessing wrong will be higher if we return bad UUTs to the aircraft, even if we correctly guess that most UUTs are good.

3. Whether the repair technician should be allowed to guess what to repair if (s)he assumes the UUT to be faulty.
4. Whether we use environmental conditioning to expose failures.

Each of these approaches will yield a different economic model and each will have advantages and limitations over competing approaches. The success of the economic analysis, therefore, is dependent on correctly predicting the probabilities and on correctly assessing the cost impact of each alternative.

II. INTRODUCTION

The organization of this paper starts with an attempt to understand FAs in light of predicted mean time between failures (MTBF). Next, we assess what happens when a faulty unit is returned to the flight line, something we call "bad actors." We assess the probabilities of bad actors as well as unnecessary service using Bayes Theorem. We create a model of the possible strategies and assign costs for each stage of the model. We then combine the probabilities and the cost factors to make predictions of economic scenarios.

III. RELIABILITY, FALSE ALARMS AND NO FAULT FOUNDS

Reliability of fielded systems is the probability that a system will fail in some period of time measured by failure rate (λ) and expressed in failures per million hours, or its reciprocal Mean Time Between Failure (MTBF).

$$\lambda = 1/\text{MTBF} \text{ and } \text{MTBF} = 1/\lambda \qquad (1)$$

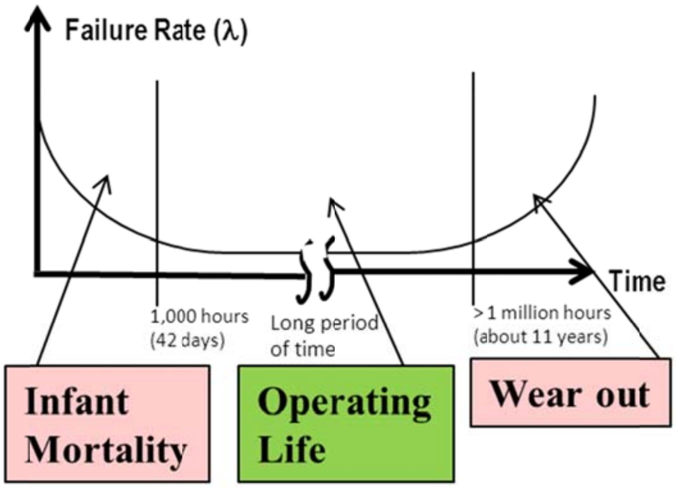


Fig. 1. Failure Rates During Avionics Product Life Cycle

As shown in Fig.1, the operating life of the product enjoys a long period of very low failure rate until we get to the wear out phase. Statistically, that does not happen with any frequency of occurrence until a million hours of operation (about 11 years). Since most avionics go into operation after the infant mortality period (about 1,000 hours or 42 days) ends, the prima facie evidence is that the UUT will likely not be faulty at all during its operating life. When a failure is indicated during the operating life period, odds are that it is not caused by an actual fault.

A cost factor to consider is what happens when an LRU is removed from the aircraft. It impacts operational Availability (A), where

$$\text{Availability (A)} = \text{MTBF}/(\text{MTBF}+\text{MTTR}) \qquad (2)$$

Because Mean Time To Repair (MTTR) is only in the denominator, it has a greater influence on Availability than MTBF does, which is in both the numerator and the denominator. For that reason, most avionics is repaired by swapping out LRUs with spares. As long as spares are available at all air field maintenance facilities, availability is not seriously impacted by MTTR. If spares are unavailable, the aircraft is grounded and the consequences can be devastating in terms of meeting mission goals and in terms of economic impact. Clearly, an FA or a bad actor can lead to aircraft grounding and scrubbing the mission.

FAs occur for many reasons, but they have no impact on NFFs until a maintenance action is taken to remove the UUT. A system can be made tolerant to FAs by taking maintenance action for some, but not all occurrences of FAs.

In [2] a distinction is made between Fraction of False Alarm (FFA), which is the "percentage of fault detections that are not due to the existence of faults" and False Alarm Rate (FAR), which is the rate of occurrence of false alarms computed over some period of time expressed in calendar days or in operating hours. FFA is usually a design specification, typically set at 2% or less. The Occurrence of False Alarm (OFA) is the number of times a false positive (FP) occurs. When a good UUT indicates that the test failed, we call it a false positive, false alarm or Type I error. So while FPs are not frequent in terms of the number of test reporting (typically, 2% to 5%), whenever they do occur they potentially create the cost of removing an otherwise fault free LRU and adding to the NFF pool. To mitigate OFAs a filtering mechanism is used, such as not reporting a failure until it fails *x* times in *y* seconds, or until it occurs *n* times.

NFFs result from several causes:

1. The removal of at least one LRU caused by real faults that are only apparent during the flight (at greater than 35,000 feet altitude, for example)
2. The removal of at least one LRU caused by real intermittent faults. Since many intermittent faults are cannot duplicates (CNDs), it is not likely that the LRU will fail the repair facility's ATE test.
3. The removal of the incorrect LRU. (The failure is real, but LRU_x is removed, when in fact LRU_y is the root cause for the failure).
4. The removal of at least one LRU caused by FAs.
5. The removal of additional LRUs due to ambiguity between LRU_a or LRU_b (or even LRU_c) as the root cause of the system failure. Diagnostic resolution typically requires that a single LRU be removed for each failure in 90% of the cases, thus adding 10% additional LRUs to the NFF pool. (If ambiguity is allowed to 3 or less LRUs, even more LRUs will be NFFs.)

It is fair, then, to estimate that most LRUs found to be NFF are in fact good. What is difficult to determine, and we believe is the essence of this paper, is whether those few NFFs that hide faulty LRUs will incur an economic impact that is too costly to live with.

IV. Cost of UUTs Returned – Good or Faulty

Life cycle cost of air vehicles in general and of avionics in particular can be calculated by taking into account the following factors:

- The original one-time (or depreciated) acquisition price of the air vehicle.
- The recurring but fixed costs to operate the air vehicle.
- The operating cost of the air vehicle, including maintenance and repair.

Fig. 2 provides a cost model for I-Level repair. When an LRU is removed from the air vehicle it is sent to I-Level repair and placed on the ATE in an attempt to confirm that it is faulty and in an attempt to diagnose the shop replaceable unit (SRU) within the LRU that is at the root cause of the LRU failure. Faulty LRUs will point to faulty SRUs, which will be replaced and/or repaired. The LRU repaired in this fashion will be retested and subsequently returned to the air vehicle.

As expected, many LRUs will not be faulty and therefore the ATE test will pass the first time. These tests will be considered NFF. If we can be certain that these units are fault free, the only conclusion we can draw is that they should be returned to the air vehicle. However, it is possible for the ATE to miss faults, and therefore, there is a chance that the LRU is in fact faulty. The cost of returning a faulty LRU to the air vehicle, called bad actor, can be substantial. So even if the percentage of cases in which bad actors occur, the cost can be significant.

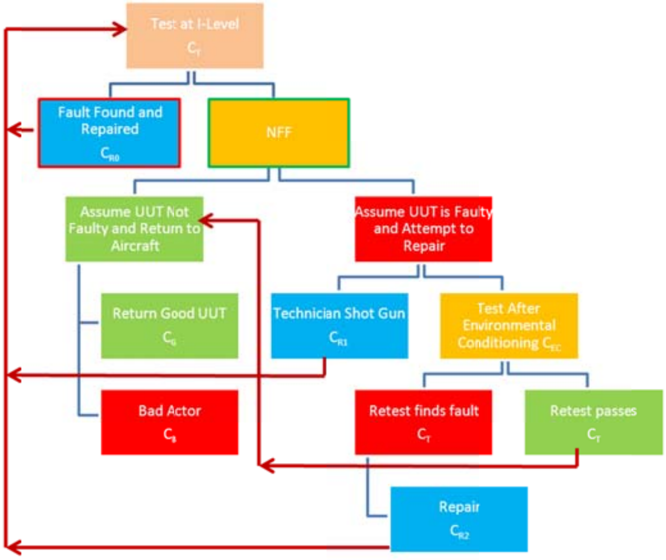


Fig. 2. Cost Model for I-Level Repair

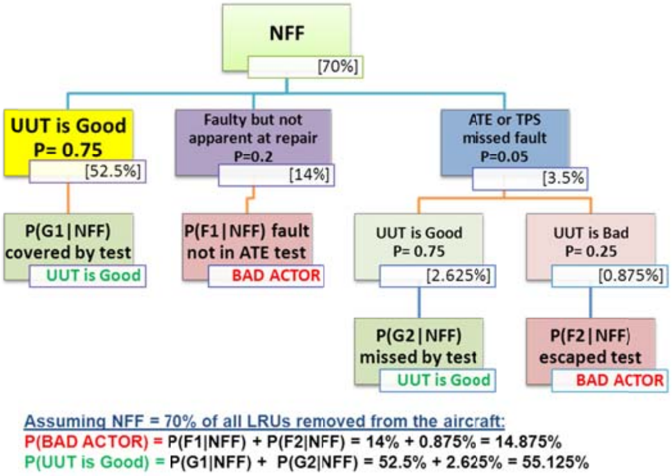
The ATE test at I-Level undergoes a cost of C_T. If it detects a fault, it is repaired at a cost of C_{R0}, but this is not a NFF-related cost. If no fault is detected by the ATE, the UUT is a NFF LRU. When NFFs occur we do not know which LRU is good and which is faulty, so we have several options to treat NFFs:

1. We will assume that all NFF LRUs are good and return them to the aircraft without repair. We recognize that some of those we return are bad actors and we will incur a cost, C_B. (Perhaps we can improve on this strategy. By assuming NFFs of previously bad actor LRUs should really be considered faulty first, we can reduce incurring C_B costs repeatedly.)
2. We will assume that all NFF LRUs are faulty and choose between two possible remedies:
    a. The first remedy is to allow the repair technician to make an educated guess on what to "fix" on an LRU that has no apparent fault indication on the ATE. The cost of this repair process is C_{R1}. After repair the LRU is retested using the ATE and if it passes this time, it will be returned to the aircraft. The probability of success with this strategy can increase if something is known about the flight conditions at the time failure was reported. A recent approach to gather such information using JTAG/IEEE-1149.1 boundary scan was suggested in [8].
    b. The second remedy is to use environmental conditioning prior to (and perhaps in conjunction with) a second ATE test. Our hope is that whatever caused the failure on the aircraft will show up. If it was an intermittent failure, perhaps the environmental conditioning will cause a weak component to expose itself. If it was a failure that only exhibits itself at high altitudes or extreme temperatures, perhaps this effort will flush it out. This environmental conditioning comes at the cost of C_{EC} and still incurs additional costs based on the outcome.
3. The test we run at environmental conditioning also incurs a test cost C_T. If the test of the LRU that has gone through these stresses passes, we assume it is good. Otherwise, we repair the LRU at a cost of C_{R2}.

V. Probability Predictions of NFF Fault Distribution

Using Bayesian analysis it has been determined that NFFs can be 70% or more of the LRUs removed from the aircraft. [1-5]. To be conservative, we will use NFF rate of 70%. Fig. 3 shows the distribution of bad actors and good UUTs given some assumptions about the comprehensiveness of the tests.

Given that we have a NFF, there are two ways the NFF can be considered good. The probability that it is good because the ATE test validated that it is good occurs with a probability of 0.75 in Fig. 3, and this probability is designated as $P(G1|NFF)$, which reads "the probability of G1, given that there is a no fault found NFF." The other way NFF can be a good UUT, $P(G2|NFF)$ is when the ATE and Test Program Set (TPS) missed the fault (which happens with a probability of 0.05), yet the UUT is good, which occurs with a probability of 0.75 for even those UUTs that are not being properly tested by the ATE.



Assuming NFF = 70% of all LRUs removed from the aircraft:
P(BAD ACTOR) = P(F1|NFF) + P(F2|NFF) = 14% + 0.875% = 14.875%
P(UUT is Good) = P(G1|NFF) + P(G2|NFF) = 52.5% + 2.625% = 55.125%

Fig. 3. Probabilities of NFF Becoming Bad Actor

Bad actors happen, when a UUT has a fault, which is beyond the capability of the I-Level ATE and TPS, P(F1|NFF), and we assume this occurs with a probability of 0.2. We also return a bad actor when the UUT is faulty, P(F2|NFF), but the fault is one that escapesthe ATE and TPS because it is a fault that was not covered.

A. *Treating all NFFs as good UUTs*

If we assume that all NFFs in Fig. 2 are good we can send them all back to the aircraft. According to our example of Fig. 3, 55.125% of the NFF UUTs would be good, but 14.875% of the NFFs returned to the aircraft would be bad actors. The cost we would incur from NFF if we took this strategy in Fig. 2 would be:

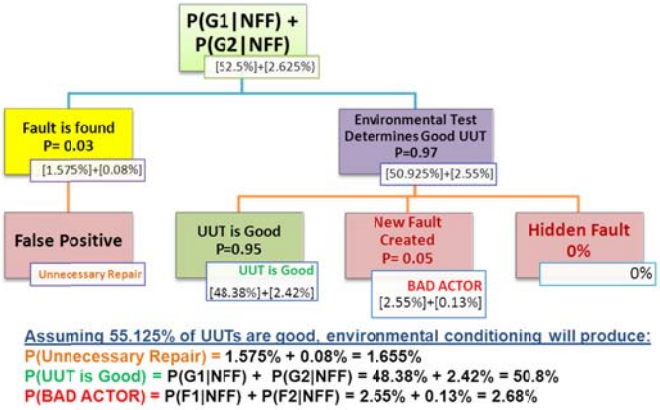
$$C_{NFF:G} = C_T + 55.125\% * C_G + 14.875\% * C_B \qquad (3)$$

where $C_{NFF:G}$ is the cost of assuming all NFF UUTs are good, C_T is the cost of testing NFF UUTs, C_G is the cost of handling and administering each good UUT and C_B is the cost of handling, administering each bad UUT as well as the consequential costs incurred from reintroducing a bad LRU on the aircraft.

B. *Environmentally conditioning all NFF UUTs*

If we assume that all NFF UUTs are faulty and resort to environmental stresses to expose those faults, we aim to reduce the percentage of bad actors.

Fig. 4 illustrates how the good UUTs among all the NFFs are affected by environmental conditioning. It includes G1 UUTs, which were found by the ATE to be fault free as well as G2 UUTs that are good despite the ATE and TPS missing tests for them. See Fig. 3 to find the condition P(G1|NFF) and P(G2|NFF). After the environmental conditioning, 50.8% of all UUTs removed from the aircraft will still be determined to be good, 2.68% will be returned as new bad actors because of faults created by the environmental stress. A false positive from the retest after the environmental stress will likely produce unnecessary repairs for 1.655% of these good UUTs.



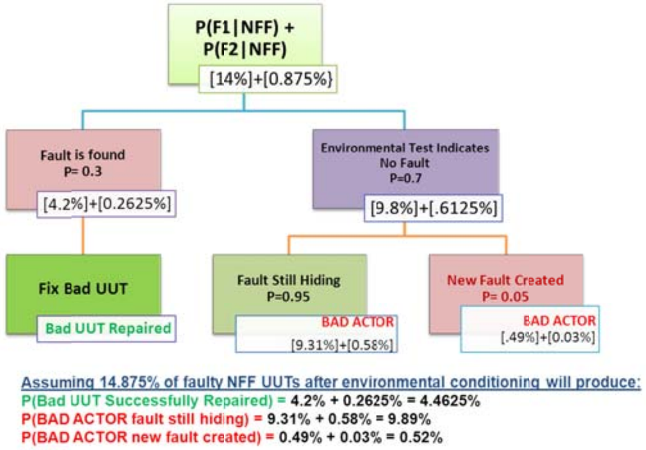
Assuming 55.125% of UUTs are good, environmental conditioning will produce:
P(Unnecessary Repair) = 1.575% + 0.08% = 1.655%
P(UUT is Good) = P(G1|NFF) + P(G2|NFF) = 48.38% + 2.42% = 50.8%
P(BAD ACTOR) = P(F1|NFF) + P(F2|NFF) = 2.55% + 0.13% = 2.68%

Fig. 4. Probabilities after Good UUT NFFs undergo environmental conditioning

Fig. 5 illustrates how the faulty UUTs among all the NFFs are affected by environmental conditioning. It includes P(F1|NFF), those that have faults not testable by the ATE and TPS at I-Level as well as P(F2|NFF), those faults that escaped the ATE and TPS test at I-Level. See Fig. 3 to find the conditions P(F1|NFF) and P(F2|NFF). As a result of the environmental conditioning, 4.4625% of the faulty UUTs are in fact repaired, while 9.89% will still have hidden faults. Additionally, 0.52% will have new faults created.

With the above information we can now formulate the cost incurred when an environmental conditioning approach is taken. The cost of this tactic, $C_{NFF:E}$ consists of the costs of

- Initial test at I-Level
- The environmental conditioning process
- Testing NFF UUTs again per Fig. 4 and 5.
- Repair of faults found
- Retesting after repair
- Administrative and other costs for good UUTs
- Administrative and other costs for bad actors



Assuming 14.875% of faulty NFF UUTs after environmental conditioning will produce:
P(Bad UUT Successfully Repaired) = 4.2% + 0.2625% = 4.4625%
P(BAD ACTOR fault still hiding) = 9.31% + 0.58% = 9.89%
P(BAD ACTOR new fault created) = 0.49% + 0.03% = 0.52%

Fig. 5. Probabilities after faulty UUT NFFs undergo environmental conditioning

In equation form we have:

$$C_{NFF:E}=C_T+C_{CE}+70\%*C_T+4.4625\%*(C_{R2}+C_T) + (50.8\%+4.46\%)*C_G+(2.68\%+9.89\%)*C_B$$

$$C_{NFF:E}= 174.4625\%*C_T+C_{CE}+4.4625\%*C_{R2} +55.26\%*C_G + 12.57\%*C_B \qquad (4)$$

To decide which strategy is better, we can calculate the difference between $C_{NFF:G}$ from Equation (3)and $C_{NFF:E}$from Equation (4):

$$C_{NFF:E}-C_{NFF:G}=74.46\%*C_T+C_{CE}+4.4625\%*C_{R2}–2.305\%*C_B \quad (5)$$

Note that in Equation (5) the cost of good UUTs, C_G, cancels out and effectively the rationale of the entire strategy depends on the elimination of 2.305% bad actors. If $2.305\%*C_B$ is greater than the environmental conditioning, extra tests and repair, it is justified. Otherwise assuming all NFFs are good is a more economic tactic.

C. NFF UUTs are determined by Technician to be Faulty and Repaired

In this strategy the technician, based on experience and any other appropriate information makes a decision to attempt to repair a UUT that was rendered NFF.

We make the following assumptions about technician repairs:

1. The technician is aware of the distribution of NFFs to be about ¾ good and about ¼ faulty, so (s)he will only attempt to repair ¼ or 25% of the UUTs.
2. Of those the technician chooses to repair, (s)he has a 60% chance of correctly identifying a bad UUT and slightly less than a 60% chance of correctly repairing the UUT, so we will assume that (s)he will correctly repair 60% of 60% or about 1/3 of the faulty UUTs and incur repair costs on about 1/3 of the good UUTs attempted.
    a. With NFF = 70%, repair will be attempted on 25% of 70% or on 17.5% of the LRUs removed from the aircraft.
    b. Of the 17.5% about ¼ will be faulty and ¾ will be good, namely 4.375% of the repairs will be on faulty UUTs, and 13.125% of the repairs will be on good UUTs.
    c. We assume that the accuracy of the repair is such that in 5% of the cases, the repair will be done incorrectly.
        i. So of the 4.375% faulty UUTs that are undergoing repairs, 95%, or 4.156% will have a correct fix.
        ii. Of the 13.125% good UUTs being repaired, 5%, or 0.65625% will result in creating a fault. 95% of that number will add repair costs but will be fixed before returning the UUT to the aircraft. However, 5% of 0.65625%, or about 0.03% will become bad actors

The cost of technician repairs of NFFs, $C_{NFF:T}$ can be calculated for the first order of iteration of the 70% NFF scenario as follows:

$$C_{NFF:T}=C_T+(17.5\%)*C_{R1}+(55.125\%+4.156\%)*C_G + (14.875\% + .03\%)\ C_B.$$

$$C_{NFF:T}= C_T+(17.5\%)*C_{R1}+(59.281\%)*C_G+(14.9\%)*C_B \quad (6)$$

- where the 17.5% represents the percentage of UUTs removed from the aircraft that are being repaired at a cost of C_{R1};
- 55.125% represents those NFF UUTs that are good;
- 4.156% of the UUTs will be correctly repaired by the technician;
- 14.875% of the NFF UUTs are bad and .03% that were good have been damaged by this attempt.

Equation (6) for $C_{NFF:T}$can be compared to Equation (3) for $C_{NFF:G}$ and to Equation (4) for $C_{NFF:E}$ to determinethe best tactic.

VI. SUMMARY AND CONCLUSIONS

We created an economic model for NFFs. NFFs can have several reasons for passing or failing the I-Level ATE test (called "screening test" by the US Air Force) after they are removed from the O-Level flight line. They could be the result of false alarms, intermittent (and therefore not easily repeatable) tests, wrong UUT removal, additional UUT removal due to diagnostic ambiguity, or the UUT could simply escape the I-Level ATE test. In analyzing all these and other causes of NFF, it is clear that we cannot easily determine which NFF UUT is good or faulty. We can, however, make a determination about the distribution of good UUTs and faulty UUTs. While most NFF UUTs are in fact good, this alone does not mean that this assumption will produce the most cost effective strategy. The fact that a bad UUT sent back to the flight line creates a greater cost than the maintenance nuisance of testing good UUTs means that it is not clear what is the best strategy to follow.

In this paper, we formulated a cost model in Fig. 2 that utilizes three distinct test strategies. The strategies are:

- All NFFs assumed to be good at a cost of $C_{NFF:G}$
- All NFFs are environmental stressed and then retested at a cost of $C_{NFF:E}$
- A technician decides on a reasonable way to "fix" UUTs he/she assumes to be faulty at a cost of $C_{NFF:T}$

For each of these strategy costs we included as input

- Cost of Test, C_T
- Cost of a Good UUT, C_G
- Cost of a Bad UUT, C_B

For some strategies other costs factors include

- Cost of Environmental Conditioning, C_{CE}
- Cost of Technician Repair, C_{R1} and C_{R2}

Table I summarizes the formulas and contains the coefficients of each term for each test strategy derived from Equations (3), (4) and (6). The coefficients are all derived from an assumption of NFF=70% of all UUTs removed from the aircraft. All percentages used as coefficients also pertain to the percentage of UUTs removed from the aircraft.

TABLE I. POSSIBLE NFF TEST STRATEGIES

		Strategies for NFF= 70%		
		All NFF assumed Good	Environmental Stress	Technician Shot Gun
Factors		$C_{NFF:G}$	$C_{NFF:E}$	$C_{NFF:T}$
Cost of Test	C_T	100.00%	174.46%	100.00%
Cost of Good UUT	C_G	55.13%	55.26%	59.28%
Cost of Bad UUT	C_B	14.88%	12.57%	14.90%
Cost of Environmental Conditioning	C_{CE}		100.00%	
Repair Cost of Technician Fix	C_{R1}			17.50%
Repair Cost after Stress Test	C_{R2}		4.46%	

Table II shows an example, where realistic cost figures are used in the formulas. The cost of test and the cost of good UUTs is assumed to be $1,000 per UUT. The cost of environmental conditioning is assumed to be $1,500 per UUT plus an additional $1,000 per UUT if a repair, C_{R2}, is required because the retest finds the UUT faulty. The same $1,000 repair cost is used when the technician selects certain UUTs to repair.

In Table II we use a $20,000 cost for a bad actor C_B. We note that our results indicate that the environmental stress strategy is the most costly and the other two strategies cost almost the same, with the “All NFF assumed Good” strategy being the best.

Tables III uses the same cost figures as Table II, with the exception that the cost of a bad actor, C_B, is increased to $50,000 per UUT. All the costs are higher than in Table II, but the ranking of the strategies have not changed.

In Table IV, we set C_B to $100,000 and “Environmental Stress” becomes the best strategy. All three strategies’ costs are close to each other.

The results indicate that the strategy is sensitive to the penalty we incur from returning faulty LRUs to the aircraft. Other factors, such as good UUT costs and test costs may have similar impact on the choice of strategy.

Also, we may contemplate a variation to our strategies in which we deal differently with UUTs that we know to have been bad actors before, or just have returned from the aircraft.

Finally, we should acknowledge that this model is based on 70% NFFs and other fault coverage assumptions we made in Fig. 3, Fig. 4 and Fig. 5. A different distribution of NFFs and other assumptions would have produced a different formula.

Additionally, this model needs to be validated with actual fielded data. In future work we will endeavor to utilize cost data from military and commercial avionics maintenance operations, where more realistic cost data is available.

TABLE II. EXAMPLE NFF ECONOMIC ANALYSIS FOR VARIOUS TEST STRATEGIES USING TYPICAL COST FACTORS AND C_B= $20,000

		Strategies for NFF= 70%		
		All NFF assumed Good	Environmental Stress	Technician Shot Gun
Factors		$C_{NFF:G}$	$C_{NFF:E}$	$C_{NFF:T}$
Cost of Test C_T	$ 1,000	100.00%	174.46%	100.00%
Cost of Good UUT C_G	$ 1,000	55.13%	55.26%	59.28%
Cost of Bad UUT C_B	$ 20,000	14.88%	12.57%	14.90%
Cost of Environmental Conditioning C_{CE}	$ 1,500		100.00%	
Repair Cost of Technician Fix C_{R1}	$ 1,000			17.50%
Repair Cost after Stress Test C_{R2}	$ 1,000		4.46%	
Cost of each NFF		***$ 4,526.25***	***$ 6,355.85***	***$ 4,747.81***

TABLE III. EXAMPLE NFF ECONOMIC ANALYSIS FOR VARIOUS TEST STRATEGIES USING TYPICAL COST FACTORS AND C_B= $50,000

		Strategies for NFF= 70%		
		All NFF assumed Good	Environmental Stress	Technician Shot Gun
Factors		$C_{NFF:G}$	$C_{NFF:E}$	$C_{NFF:T}$
Cost of Test C_T	$ 1,000	100.00%	174.46%	100.00%
Cost of Good UUT C_G	$ 1,000	55.13%	55.26%	59.28%
Cost of Bad UUT C_B	$ 50,000	14.88%	12.57%	14.90%
Cost of Environmental Conditioning C_{CE}	$ 1,500		100.00%	
Repair Cost of Technician Fix C_{R1}	$ 1,000			17.50%
Repair Cost after Stress Test C_{R2}	$ 1,000		4.46%	
Cost of each NFF		***$ 8,988.75***	***$ 10,126.85***	***$ 9,217.81***

TABLE IV. EXAMPLE NFF ECONOMIC ANALYSIS FOR VARIOUS TEST STRATEGIES USING TYPICAL COST FACTORS AND C_B= $100,000

		Strategies for NFF= 70%		
		All NFF assumed Good	Environmental Stress	Technician Shot Gun
Factors		$C_{NFF:G}$	$C_{NFF:E}$	$C_{NFF:T}$
Cost of Test C_T	$ 1,000	100.00%	174.46%	100.00%
Cost of Good UUT C_G	$ 1,000	55.13%	55.26%	59.28%
Cost of Bad UUT C_B	$ 100,000	14.88%	12.57%	14.90%
Cost of Environmental Conditioning C_{CE}	$ 1,500		100.00%	
Repair Cost of Technician Fix C_{R1}	$ 1,000			17.50%
Repair Cost after Stress Test C_{R2}	$ 1,000		4.46%	
Cost of each NFF		***$ 16,426.25***	***$ 16,411.85***	***$ 16,667.81***

REFERENCES

[1] L. Y. Ungar, Causes and Costs of No Fault Found Events, Proc. of IPC APEX, Feb 2015.

[2] L. Y. Ungar, The True Nature of False Alarms, Proc. of AutoTest 2014.

[3] M. iLARSLAN and L. Y. Ungar, Mitigating the Impact of False Alarms and No Fault Found Events in Military Systems, IEEE Instrumentation & Measurement Magazine, August 2016, pp. 15-21.

[4] S. Kahn, I. K. Jennions, P. Phillips, C. Hockley, **No Fault Found: The Search for the Root Cause,** SAE International, 2015. http://books.sae.org/r-441/

[5] J. A. Erkoyuncu, S. Kahn, et. al. A Framework to Estimate the Cost of No Fault Found Events, International Journal of Production Economics, Elsevier Ltd., March 2016, pp. 207-222.

[6] G. Hubby, No Fault Found, 2015Aerospace Survey Results, NFF Symposium, 2015.

[7] Qi H, Ganesan S, Pecht M. "No-fault-found and intermittent failures in electronic products," Microelectronics Reliability 48, Elsevier Ltd. 2008, p. 663-674.

[8] L. Y. Ungar and M. D. Sudolsky, Tapping Into Boundary Scan Resources for Vehicle Health Management, Proc. of AUTOTESTCON, Sep. 2016.

[9] Sorensen B.,"Digital averaging – the smoking gun behind 'No-Fault-Found,'" Air Safety Week, Feb. 24, 2003.

[10] K. Anderson, Reducing NFF and Improving Operational Availability Through Intermittent Fault Detection, NFF Symposium, 2015 http://www.through-life-engineering-services.org/news-and-events/events/nff-symposium