CRM D0003183.A2/Final
June 2001

TACAIR Material Readiness in Operation Allied Force

Peter J. Francis

CNA
4825 Mark Center Drive • Alexandria, Virginia 22311-1850

Approved for distribution: June 2001

Alan J. Marcus, Director
Infrastructure and Readiness Team
Resource Analysis Division

This document represents the best opinion of CNA at the time of issue.
It does not necessarily represent the opinion of the Department of the Navy.

Approved for Public Release; Distribution Unlimited. Specific authority: N00014-00-D-0700.
For copies of this document call: CNA Document Control and Distribution Section at 703-824-2123.

Contents

THIS PAGE INTENTIONALLY LEFT BLANK

Introduction

This work was done as part of a larger study conducted for N814. The purpose of the larger study was to examine the link between mission performance and readiness drivers using data from CVN–71's combat operations during Operation Allied Force (OAF). In this part of the project, we looked specifically at material readiness of the embarked airwing (CVW–8).

Our original intent was to estimate the parameters for a complete Markov model of aircraft material condition. The transition matrix shown in figure 1 gives the general structure of such a model. Each aircraft was to be considered in one of three discrete states: airborne, not airborne but mission capable, or not mission capable. Transition probabilities between the states were to work as shown in figure 1. For example, p1 represents the probability that an aircraft that is not mission capable during one period would be in the same state during the next period.

Figure 1. Transition matrix representing a Markov model of aircraft material condition

Time *t*	Time *t*+1		
	NMC	MC on board	In flight
NMC	p1	1 - p1	0
MC on board	p2	p3	1 - p2 - p3
In flight	p4	p5	1 - p4 - p5

We were unable to implement a complete realization of this model because of problems that included missing data and resource constraints. However, we were able to make substantial progress on two components of the process in figure 1, and we present these results below.

Data

Data sources were our Maintenance Action Form (MAF) database for information on sorties and transitions between states for individual airframes, and ISIS data that allowed us to link pilots to particular sorties. Information on aircraft age (for F/A–18s) came separately from NAVAIR. For reasons that we do not understand, NALCOLMIS data for this battlegroup are not available for April of 1999; we are therefore limited to May and early June as the only periods of OAF for which we have data. Summary statistics are listed in table 1, and figure 2 shows how the sortie durations were distributed across squadrons and over time.

Table 1. Summary statistics

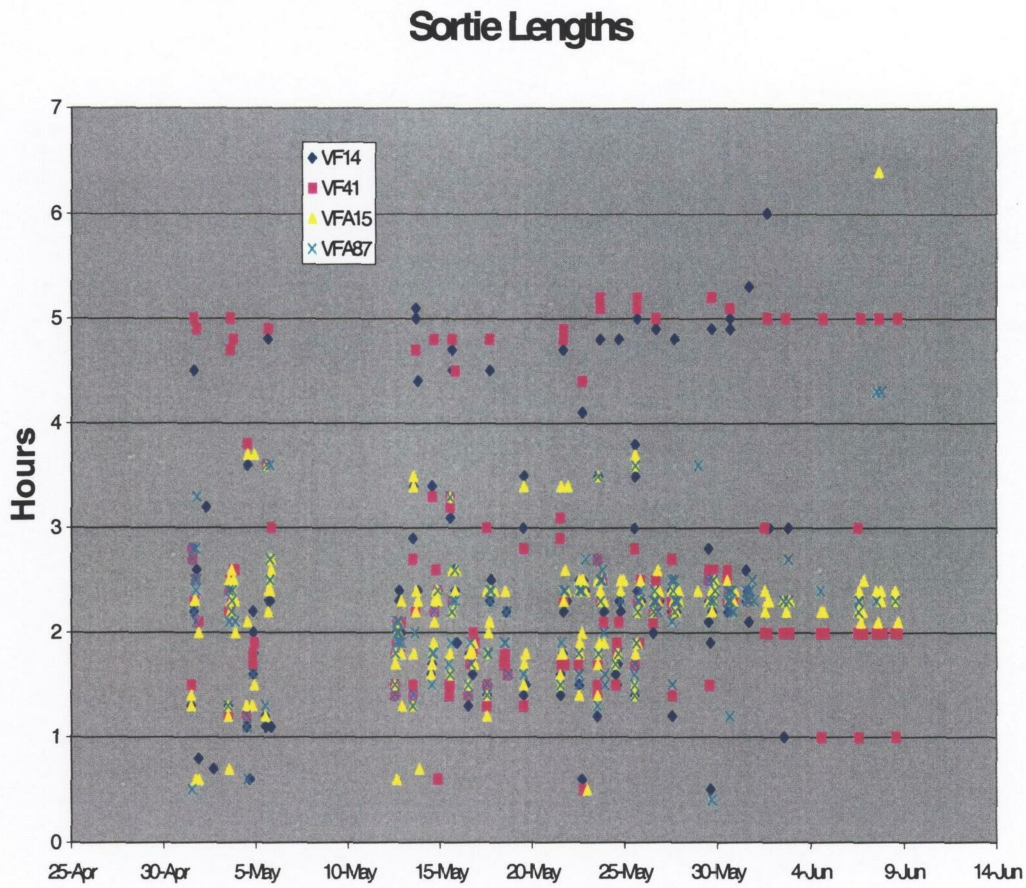
Number of sorties	814
F–14 sorties	48.8%
Training sorties	30.2%
Support sorties	3.2%
Percent down after sorties	25.3%
Average length of sorties	2.35 hours
Average pilot experience	935 hours
Average a/c age (F/A–18s only)	7.25 years
Average down spell after sortie	17.9 hours

Down-after-sortie model

The failure-after-sortie model corresponds to probability p4 in figure 1. We estimated a binary dependent variable (probit) model where the dependent variable was whether the aircraft went to a "down" status within one hour of completing a sortie. Full model results are in appendix A, but our principal conclusions are as follows:

- The type of flight mattered, with training and overhead flights being more likely to result in a subsequent down spell than operational flights. However, it isn't clear that this relationship is directly causal, at least for the training flights. Planes that were due to go

Figure 2. Distribution of sortie duration across squadrons and over time



down later anyway might well be those that were designated for training activity. Also, most of the overhead flights were functional check flights that occurred immediately after a major overhaul or repair. Thus, it perhaps should come as no surprise that there is a greater-than-usual need for maintenance work after the check flight because some aspects of the overhaul may not have been done correctly.

- There were marked differences between squadrons, and again, it isn't clear how to interpret these differences. A greater tendency to take a plane down may be due to more alert crews, but it could also be due to poor earlier work.

- Because aging platforms are an increasing source of concern for the Navy, we tried to identify age effects. At the time we did this work, we had age data for the F/A–18s in CVW–8 only. We estimated this same model for just those aircraft and included age as an independent variable. For F/A–18s, the model produced an estimate that an additional year of age increased the propensity to go down after a sortie by 3.6 percent. However, this result was not statistically significant.

- We included sortie length and pilot characteristics in the model, but neither of these had a statistically significant effect.

- We can get a rough indication of whether this type of model is a good fit by simply counting actual and predicted outcomes. When we did that here, we found that, for the full sample of sorties, there were ten observations (sorties) where the estimated probability of a plane going down was greater than 50 percent. In six of the ten sorties, the planes did in fact go down within an hour of landing.

Downtime duration model

The other portion of a Markov-type model that we examined was a duration (hazard) model of aircraft downtime. This would loosely correspond to estimating p1 in figure 1. We estimated it using the data from the sortie database—that is, we used only those down spells that were attributed to sorties in the model of the previous section. Therefore, this model doesn't use down spells for aircraft that were taken down more than one hour after they returned from a flight, and, consequently, it doesn't fully reflect the effects of routine scheduled maintenance.

We present complete documentation (LIMDEP output) in appendix B, but this is a summary of the key results:

- In general, sortie-specific variables had little effect on downtime. The exception was if the sortie was for training: There was a statistically significant increase in downtime associated with sorties with a training flight purpose code. It isn't clear why this should be so, although our speculations concerning the selection of aircraft for training purposes may be appropriate here too.

- F–14s stayed down longer that F/A–18s. This is not surprising because the F/A-18 is well known for being relatively easy to work on.
- The age effect was again positive and not statistically significant.
- We chose the Weibull as the distribution for the hazard function because of its generality. (It allows for either an increasing or decreasing hazard function, and the constant-hazard special case is simply the exponential distribution.) From the actual model estimation, we can conclude that the downtime durations seem to follow a distribution that is significantly different from the exponential and has a decreasing hazard. This is consistent with previous CNA research on logistics system performance. (See [2].)

Summary and conclusions

We have identified some of the variables that would seem to be relevant to the determination of some of the transition probabilities for a Markov model of aircraft availability. These models can probably be refined even further. One important factor that was not allowed for was the length of time on station; this would likely have a deleterious effect on both people and machines. Characteristics of the individual maintainers was another factor that we could not incorporate due to data limitations. We hope to be able to match maintainer personnel data to MAFs in the future.

Note that there is a considerable similarity between the framework we are considering here and earlier work on sortie-generation models. (See [3, 4].) However, in those models, the probability distributions were seen as essentially fixed, whereas in this analysis, we are trying to allow for the possibility that some factors—"squawk rates," for example—can be expected to vary at least somewhat in response to factors that we can measure.

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix A. Down-after-sortie model results

We did all our statistical modeling with the LIMDEP econometric software package. Text output from the down-after-sortie model follows. We present results present for the entire CVW–8 fighter and attack population, and then for F/A–18s only. Most of the variables are self-explanatory, but two of them merit comment. FLTHRSQR, which is the square of flight hours, was introduced to accommodate possible nonlinearities in the relationship. SFTI refers to the rating system for pilots discussed in [5, pg. 56]. Hours refers to the number of hours the pilot had flown on the particular T/M/S.

I. Combined F–14s and F/A–18s

```
+---------------------------------------------+
| Binomial Probit Model                       |
| Maximum Likelihood Estimates                |
| Dependent variable             UPORDOWN     |
| Weighting variable                  ONE     |
| Number of observations              814     |
| Iterations completed                  5     |
| Log likelihood function       -416.9280     |
| Restricted log likelihood     -460.4669     |
| Chi-squared                    87.07775     |
| Degrees of freedom                    9     |
| Significance level             .0000000     |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	-1.478689920	.48333903	-3.059	.0022	
VF14	.1788728074	.13695153	1.306	.1915	.26044226
VF41	-.3889974744E-01	.14187899	-.274	.7839	.22727273
VFA15	-.9651991829	.16151980	-5.976	.0000	.28992629
FLTHRS	.4181767389	.29599695	1.413	.1577	2.3484029
FLTHRSQR	-.5578390117E-01	.44413665E-01	-1.256	.2091	6.4334890
TRAINING	.3781438865	.14247535	2.654	.0080	.30221130
SUPPORT	.5890132056	.30143126	1.954	.0507	.31941032E-01
SFTI	.3169089817E-01	.57949122E-01	.547	.5845	3.0294840
HOURS	.1168902453E-03	.12453372E-03	.939	.3479	934.63857

```
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)



+-------------------------------------------+
| Partial derivatives of E[y] = F[*]   with |
| respect to the vector of characteristics. |
| They are computed at the means of the Xs. |
| Observations used for means are All Obs.  |
+-------------------------------------------+
+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
         Index function for probability
 Constant    -.4421851784       .14321719   -3.088   .0020
 VF14      .5517223277E-01  .43501586E-01    1.268   .2047     .26044226
 VF41     -.1153825076E-01  .41738818E-01    -.276   .7822     .22727273
 VFA15       -.2415348880   .31440892E-01   -7.682   .0000     .28992629
 FLTHRS       .1250509341   .88455194E-01    1.414   .1574     2.3484029
 FLTHRSQR -.1668153272E-01  .13274642E-01   -1.257   .2089     6.4334890
 TRAINING     .1189752113   .46683921E-01    2.549   .0108     .30221130
 SUPPORT      .2067590720       .11701175    1.767   .0772 .31941032E-01
 SFTI      .9476797851E-02  .17327290E-01     .547   .5844     3.0294840
 HOURS     .3495468067E-04  .37259672E-04     .938   .3482     934.63857
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
+----------------------------------------+
| Fit Measures for Binomial Choice Model |
| Probit   model for variable UPORDOWN   |
+----------------------------------------+
| Proportions P0= .746929    P1= .253071  |
| N =      814 N0=      608    N1=     206  |
| LogL =   -416.92804 LogL0 =   -460.4669  |
+----------------------------------------+
|     Efron |  McFadden  |  Ben./Lerman  |
|    .09517 |     .09455 |        .65766 |
|    Cramer | Veall/Zim. |      Rsqrd_ML |
|    .09454 |     .18205 |        .10145 |
+----------------------------------------+
| Information  Akaike I.C. Schwartz I.C. |
| Criteria         1.04896     900.87569 |
+----------------------------------------+
Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.
Threshold value for predicting Y=1 = .5000
            Predicted
------  ----------  +  -----
```

```
Actual       0     1  |  Total
------  ----------  +  -----
  0        604     4  |    608
  1        200     6  |    206
------  ----------  +  -----
Total      804    10  |    814

--> Probit; lhs=Upordown; rhs=one,acage,vfa15,Flthrs,flthrsqr, training,
supp...
Normal exit from iterations. Exit status=0.
```

II. F/A–18s only.

```
+--------------------------------------------+
| Binomial Probit Model                        |
| Maximum Likelihood Estimates                 |
| Dependent variable               UPORDOWN    |
| Weighting variable                    ONE    |
| Number of observations                417    |
| Iterations completed                    5    |
| Log likelihood function         -168.7557    |
| Restricted log likelihood       -193.4127    |
| Chi-squared                      49.31406    |
| Degrees of freedom                      8    |
| Significance level               .0000000    |
+--------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	-2.446023800	1.5340101	-1.595	.1108	
ACAGE	.1593963571	.16982052	.939	.3479	7.2481439
VFA15	-.9711541856	.17341141	-5.600	.0000	.56594724
FLTHRS	.4450233708	.61628718	.722	.4702	2.1491607
FLTHRSQR	-.7614385694E-01	.12148838	-.627	.5308	4.9658993
TRAINING	.1825954579	.22798726	.801	.4232	.33093525
SUPPORT	.6838744847	.45083337	1.517	.1293	.33573141E-01
SFTI	.9080547778E-01	.72121584E-01	1.259	.2080	2.8848921
HOURS	-.1789763417E-03	.18051210E-03	-.991	.3214	847.77410

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

```
+---------------------------------------------+
| Partial derivatives of E[y] = F[*]   with |
| respect to the vector of characteristics. |
| They are computed at the means of the Xs. |
| Observations used for means are All Obs.  |
+---------------------------------------------+
+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
          Index function for probability
 Constant    -.5514477497       .34376591   -1.604   .1087
 ACAGE     .3593536678E-01  .38330485E-01     .938   .3485     7.2481439
 VFA15       -.2338379454   .41770843E-01   -5.598   .0000     .56594724
 FLTHRS       .1003290060       .13831590     .725   .4682     2.1491607
 FLTHRSQR -.1716637367E-01  .27281959E-01    -.629   .5292     4.9658993
 TRAINING  .4253006984E-01  .54656587E-01     .778   .4365     .33093525
 SUPPORT      .2042692970       .16251556    1.257   .2088  .33573141E-01
 SFTI      .2047178624E-01  .16265249E-01    1.259   .2082     2.8848921
 HOURS    -.4034960776E-04  .40713239E-04    -.991   .3217     847.77410
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

+----------------------------------------+
| Fit Measures for Binomial Choice Model |
| Probit   model for variable UPORDOWN   |
+----------------------------------------+
| Proportions P0= .824940   P1= .175060  |
| N =      417 N0=      344   N1=     73  |
| LogL =  -168.75566 LogL0 =  -193.4127  |
+----------------------------------------+
|     Efron |  McFadden  |  Ben./Lerman  |
|    .11871 |    .12748  |       .74516  |
|    Cramer | Veall/Zim. |     Rsqrd_ML  |
|    .11779 |    .21976  |       .11153  |
+----------------------------------------+
| Information  Akaike I.C. Schwartz I.C. |
| Criteria         .85255    391.80909   |
+----------------------------------------+
Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.
Threshold value for predicting Y=1 = .5000
            Predicted
------  ----------  +  -----
```

```
Actual         0     1  |  Total
------    ----------    +  -----
  0          343     1  |    344
  1           72     1  |     73
------    ----------    +  -----
Total        415     2  |    417
```

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix B. Downtime hazard model results

Here we give the text output for the downtime hazard model. As in appendix A, we present combined F–14 and F/A–18 results first, followed by separate results for F/A–18s only. Note that it is necessary to take the natural logarithm of downtime for use in this routine. The "sigma" in this output is the parameter that determines the slope of the hazard; the fact that it is significantly different from one in the first regression establishes that the hazard function in that case is not exponential. (It is borderline significant in the second regression.)

I. Combined results for F–14s and F/A–18s

Loglinear survival model: WEIBULL	
Maximum Likelihood Estimates	
Dependent variable	LNDWNTIM
Weighting variable	ONE
Number of observations	208
Iterations completed	14
Log likelihood function	-417.9449

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
RHS of hazard model					
Constant	2.496620695	1.0964933	2.277	.0228	
VF14	-1.659409229	.34949381	-4.748	.0000	.42788462
VF41	-.6713862412	.33514312	-2.003	.0451	.28846154
VFA15	-1.110724834	.87002803	-1.277	.2017	.43269231E-01
FLTHRS	.7252487158	.70132916	1.034	.3011	2.4639423
FLTHRSQR	-.1399716072	.10076648	-1.389	.1648	7.3610096
TRAINING	-.8916738957	.31887733	-2.796	.0052	.35096154
SUPPORT	-.2672918828	.54106707	-.494	.6213	.52884615E-01

```
        Ancillary parameters for survival
Sigma        1.691159392   .97149294E-01   17.408    .0000
(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)



    +-----------------------------------------------------------------+
    | Parameters of underlying density at data means:                 |
    | Parameter   Estimate   Std. Error    Confidence Interval        |
    | ------------------------------------------------------------    |
    | Lambda        .13884      .02211       .0955 to       .1822     |
    | P             .59131      .03397       .5247 to       .6579     |
    | Median       3.87515      .61717      2.6655 to      5.0848     |
    | Percentiles  of  survival  distribution:                        |
    | Survival       .25        .50        .75        .95             |
    | Time         12.51       3.88        .88        .05             |
    +-----------------------------------------------------------------+
--> Reject; age < 0 $
--> Survival; lhs=LnDwnTim;
    rhs=one,age,vfa15,Flthrs,flthrsqr, training, support;
    model=Weibull $
Normal exit from iterations. Exit status=0.
```

II. Results for F/A–18s only

```
              +---------------------------------------------+
              | Loglinear survival model: WEIBULL           |
              | Maximum Likelihood Estimates                |
              | Dependent variable              LNDWNTIM    |
              | Weighting variable                   ONE    |
              | Number of observations                59    |
              | Iterations completed                  14    |
              | Log likelihood function        -108.6682    |
              +---------------------------------------------+
+---------+-------------+---------------+--------+---------+----------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
RHS of hazard model					
Constant	.7007576221	4.8927149	.143	.8861	
AGE	.5270809643	.39845108	1.323	.1859	7.3998805
VFA15	-.9520432114	.65406279	-1.456	.1455	.15254237
FLTHRS	-.2352836102	3.1695339	-.074	.9408	2.0474576
FLTHRSQR	-.5385881816E-01	.76223681	-.071	.9437	4.5077965
TRAINING	-1.545007594	.78947811	-1.957	.0503	.40677966
SUPPORT	-2.793202177	1.5556986	-1.795	.0726	.84745763E-01
Ancillary parameters for survival					
Sigma	1.302560425	.16626092	7.834	.0000	

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Parameters of underlying density at data means:

Parameter	Estimate	Std. Error	Confidence Interval		
Lambda	.05692	.01085	.0357	to	.0782
P	.76772	.09799	.5757	to	.9598
Median	10.89991	2.07784	6.8273	to	14.9725

Percentiles of survival distribution:

Survival	.25	.50	.75	.95
Time	26.89	10.90	3.47	.37

THIS PAGE INTENTIONALLY LEFT BLANK

Bibliography

[1] Peter Francis and Geoffrey Shaw. *Effect of Aircraft Age on Maintenance Costs,* March 2000 (CNA Annotated Briefing D0000289.A2)

[2] Walter R. Nunn and Ronald H. Nickel. *Part Replacement Time Analysis,* Apr 2000 (CNA Research Memorandum D0000743.A1)

[3] Walter R. Nunn. *A Simple Monte Carlo Sortie-Generation Model for Carrier Aircraft,* Apr 1986 (CNA Research Contribution 542)

[4] Walter R. Nunn. *A Visual Basic Version of the Sortie-Generation Model Muir3,* June 1996 (CNA Research Memorandum 96–85)

[5] Laura J. Junor et al. *Trends in Interdeployment Training Readiness: A Study of the Bathtub,* Oct 2000 (CNA Research Memorandum D0002077.A2)

THIS PAGE INTENTIONALLY LEFT BLANK

List of figures

THIS PAGE INTENTIONALLY LEFT BLANK

List of tables