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PREDICTIVE CORROSION MODELING

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This report for a program to develop a predictive corrosion model for aircraft summarizes the work completed in Task III. The corrosion rate equations and models developed in Task II were converted into a VAX-11 FORTRAN program which enables the analysis of specific points on the C-5 aircraft and, utilizing environmental factors and the time periods an aircraft has been at various Air Force bases, gives recommended times for inspection and maintenance. The FORTRAN computer program includes a crack growth module which calculates the remaining flight hours until a theoretical crack grows to half its critical length, a corrosion module which calculates the remaining hours until exposed aircraft alloys corrode to a depth of 3 mils, and a coating degradation module which computes the optimum time remaining until the next paint renewal or complete repaint operation. Volume I describes the program effort. Volume II contains computer program printouts.

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FOREWORD

This report summarizes the work performed in Task III of a program to develop a Predictive Corrosion Model for Air Force aircraft. The project is authorized under Contract No. F33615-85-5058. The object of Task III was to convert the equations and models developed in Task II into a VAX-11 FORTRAN program which can be used to establish optimum inspection and maintenance schedules for both existing new aircraft.

The Task III portion of the program was accomplished by a research team composed of the following Lockheed-Georgia personnel:

D. M. O'Rourke of the Propulsion and Acoustics Department

D. J. Cannington and B. M. Payne of the Structures Development Department

W. T. Rowell of the Reliability Engineering Department

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Special acknowledgment is made to Fred H. Meyer, Jr., the USAF Project Engineer, and to Dr. Fred Chuang, Air Logistics Command, for their guidance in accomplishing the desired objectives.

Volume I describes the program effort only. Volume II contains a printout of computer software.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

This is a summary report for an Air Force program to reduce corrosion repair costs by optimizing inspection and maintenance scheduling of C-5 aircraft.

At the present time, inspection and maintenance operations are based on calendar time or flying hour intervals dictated by potential fatigue damage to structure or wear of engine parts. Any corrosion damage detected during these inspections is repaired. This maintenance scheduling procedure does not take into consideration the wide variation of environmental conditions at Air Force bases. An aircraft which operates in a dry environment requires less frequent inspections and fewer maintenance manhours than one which flies from island to island in the South Pacific.

Fatigue cracking, general corrosion and degradation of protective coating systems are strongly influenced by moisture, salt water, ultraviolet radiation and atmospheric contaminants such as sulfur dioxide, ozone and oxides of nitrogen. The aluminum, steel and magnesium alloys used in aircraft construction are affected in varying degrees. The key to this predictive corrosion modeling program is relating the kinetics of corrosion of aircraft alloys and the degradation of aircraft coating systems to the environments in which aircraft operate.

Dr. Summitt of Michigan State University(1) has developed a system for rating the corrosivity of Air Force bases. Another development of the past few years is an improved understanding of the mechanisms of corrosion of aircraft alloys. There is also a greater knowledge of the factors which cause the deterioration of paint systems. Much of this knowledge has been integrated into a predictive corrosion computer model which will enable accurate forecasts of corrosion problems on aircraft operating in any specific type of environment.

The initial computer program is designed for the C-5A aircraft. However, with only slight modification, it may be used for any aircraft that has a crack monitoring program. The C-141, C-130 and B-52 aircraft fleets have such programs.

2.0 OBJECTIVE AND SCOPE

2.1 Objective

The objective is to develop a corrosion prediction model which can be used to optimize:

1. Field and depot level inspection programs for existing aircraft weapons systems.
2. Analytical Condition Inspection (ACI) selection and scheduling.
3. Inspection programs for new aircraft systems entering the Air Force inventory.

2.2 Scope

This program to incorporate corrosion rate data and prediction technology into inspection and maintenance scheduling consists of the following tasks:

Task I - Review and evaluate current Air Force maintenance programs and recent work on aircraft corrosion mechanisms and fracture mechanics.

Task II - Develop corrosion rate equations for aircraft corrosion processes and degradation rate equations for aircraft coating systems and incorporate them into a corrosion prediction model.

Task III - Convert the equations and models developed in Task II into a VAX-11 FORTRAN program to establish (1) Analytical Condition Inspection selection and scheduling, (2) inspection programs for new aircraft, and (3) field and depot level inspection programs for aircraft already in operation.

Task IV - Validate the computerized corrosion forecasting models and maintenance scheduling decision logic by comparing the predictions of the model with actual corrosion histories of the C-5A and/or C-141 fleets.

Task V - Evaluate the efficiency of a new maintenance scheduling decision logic which integrates the corrosion forecasting models with Reliability Centered Maintenance's (RCM) Failure Mode Effects and Criticality Analysis (FMECA) and analytical models developed for the Aircraft Structural Integrity Program (ASIP).

3.0 PROGRAM SCHEDULE

Figure 1 is a master schedule chart which shows the plan for the entire program.

30 MONTH PROGRAM SCHEDULE

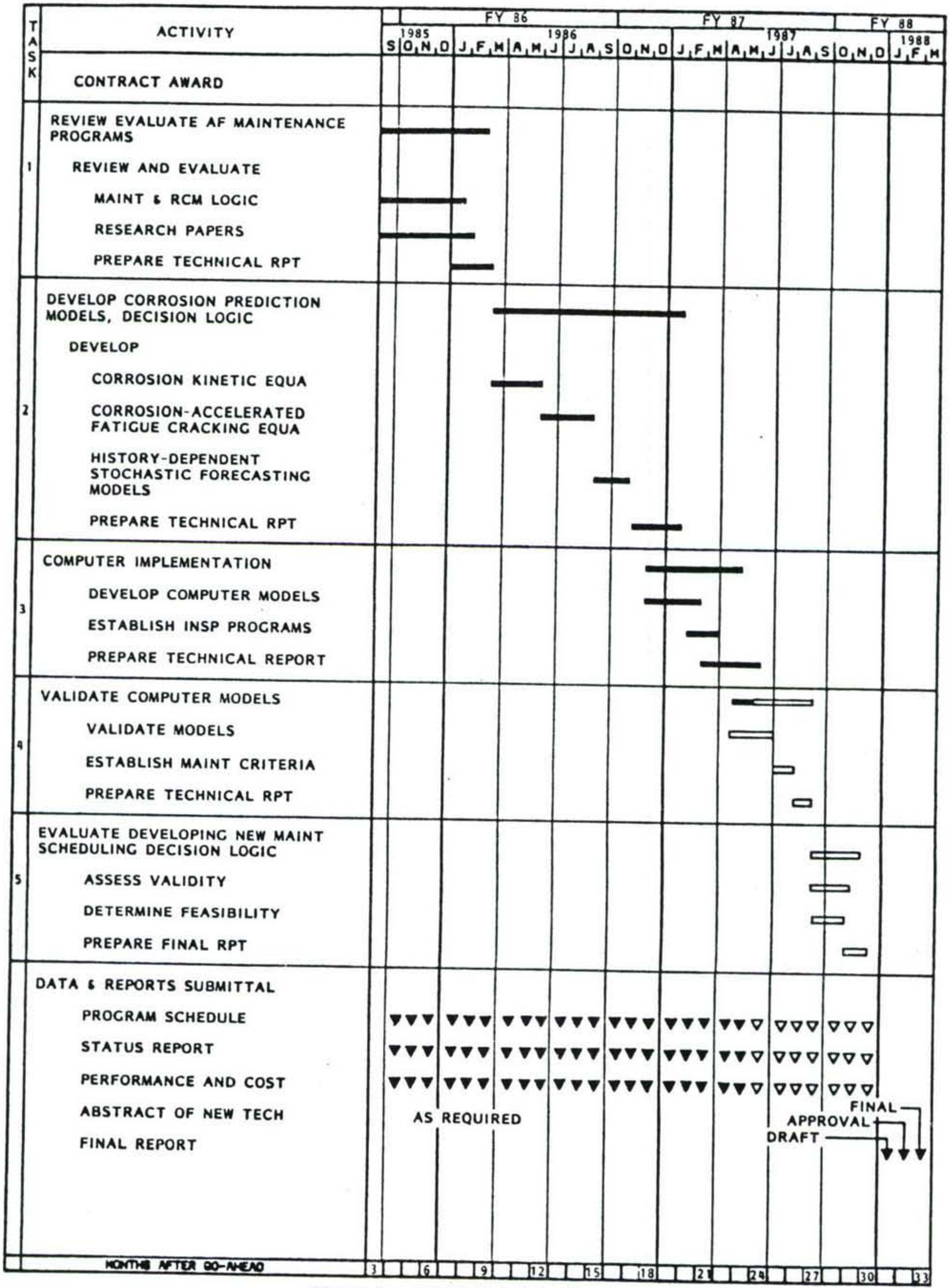


Figure 1. Master Schedule Chart

4.0 TECHNICAL PROGRESS

In Task III the corrosion rate equations and Air Force maintenance scheduling information obtained in Tasks I and II were integrated into a FORTRAN computer program which is compatible with existing Air Force structural analysis programs.

The logic involved and the procedures which were used are described in the following sections:

4.1 Corrosion Rate Equations

The computer program is based on the following types of corrosion and coating failure:

1. Corrosion Fatigue
2. Stress Corrosion Cracking
3. General Corrosion (including exfoliation and pitting)
4. Coating Degradation

After completing the comprehensive literature survey and reviewing scores of papers relating to fracture mechanics and corrosion rates of aircraft alloys in various environments, the equations in the following sections were selected for use in the predictive corrosion modeling program.

4.1.1. Corrosion Fatigue

The C-5 crack tracking program is based on the Forman(2) equation which takes into consideration the load ratio, R (minimum stress/maximum stress). The relationship is expressed as:

$$da/dN = \frac{C(\text{delta } K)}{(1-R)K_c - \text{delta } K}$$

where

delta K = difference between the maximum and minimum values of K
K_c = the critical stress intensity factor for fracture
C = material constant

This equation by itself is not adequate for the full range of da/dN data. The C-5 Crack Monitoring Program utilizes the Forman equation and parametric data to correct for variations in load ratios. As used in the C-5 Crack Monitoring Program, the constants in the Forman equation are based on experimental da/dN vs. delta K data obtained under conditions of 100 percent relative humidity.

For use in the predictive corrosion modeling computer program, the Forman equation was modified to include a Corrosivity Factor (CF).

$$da/dN = \frac{C\ (\text{delta } K)}{(1-R)K - \text{delta } K} \times CF$$

where

$$CF = \frac{da/dN\ (\text{in actual environment})}{da/dN\ (\text{obtained at } 100\%\ \text{humidity})}$$

The Corrosivity Factors were determined by plotting da/dN data vs delta K for specific aircraft alloys in dry air, distilled water, and in 3.5 percent NaCl solution on the same plot as illustrated in Figure 2. Then, assuming an average delta K value of 10 ksi in. (the average stress intensity encountered in a normal aircraft mission), the values of da/dN for each environment were read off and converted to Corrosivity Factors using the above formula. Since 3.5 percent NaCl is a more corrosive environment than 100 percent moisture, the factor for a salt/air environment would be greater than 1. Conversely, for a dry environment, the factor is less than one.

Based on the PACER LIME(1) data for Air Force Bases, each base was assigned a set of Corrosivity Factors corresponding to its environmental conditions.

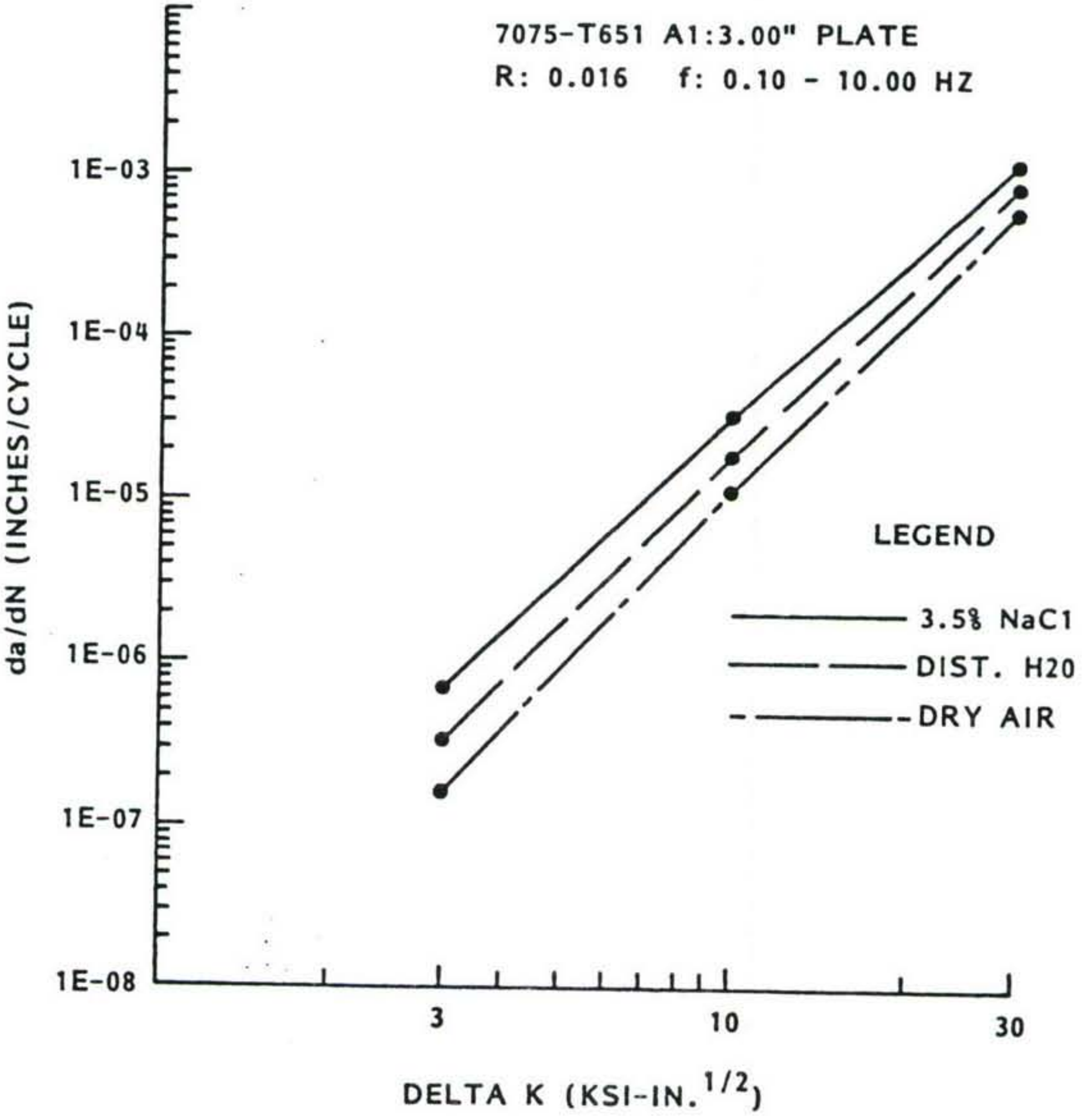


Figure 2., da/dN vs Delta K Plots for 7075-T651 Aluminum

Corrosivity Factors were calculated for 7075-T651, 7075-T73 and 7175-R73 aluminum, and for 4340 and 300M steel. The fatigue cracking data used to develop the Corrosivity Factors were obtained from the USAF Damage Tolerant Design Handbook(3).

4.1.2 Stress Corrosion Cracking

No single equation was found which defines the diverse assortment of da/dt vs. delta K curves for aluminum and steel alloys in various environments. The plots vary for each alloy and for the same alloy in various environments. Fortunately, the design handbook contains data for the more common aircraft alloys in dry, moist and salt water environments. In the predictive corrosion modeling computer program the theoretical stress intensity at each crack tip will be calculated. Whenever KIscc is exceeded, the ground time and the crack growth data from Reference 3 will be used to calculate the amount of stress corrosion cracking occurring during any given period of operation.

4.1.3 General Corrosion

Damage functions for metals in contaminated environments follow the general model

$$M = AT^B$$

where M is metal loss by corrosion (either penetration depth or weight loss), T is exposure time, and A and B are empirical constants determined by the environmental conditions, the metal involved and the type of corrosion product on the metal. The exponent B theoretically takes on the value of approximately 1/2 when corrosion is limited by the diffusion rate of the reactive species through a semi-permeable film of reaction products. This would be the case for most aluminum alloys. When the corrosion products are flocculant or soluble and offer no protection, as is generally true for steel, linear corrosion kinetics are observed and B = 1.

The Task I literature search revealed only scattered data for the corrosion of aircraft alloys in the range of environments encountered by aircraft - mild, industrial, humid, and marine. It was, therefore, necessary to conduct corrosion tests with some of the more widely used alloys in solutions with compositions simulating those of condensate and rainfall encountered by aircraft under service conditions.

In Task II, potentiostatic polarization tests were conducted with 7075-T5 and 7075-T73 aluminum and with 4340 and 300M steel in nitric and sulfurous acid solutions in the pH range of 4.0 to 6.0 and also in acid solutions containing 3 1/2% NaCl. Using linear regression mathematical techniques, these test results and the data obtained from the literature search were used to determine the constants A and B for the equations which represent the corrosion rates of specific alloys in various environments. The constants which were developed for the major aircraft alloys in mild, moderate, severe and very severe environments are summarized in Figures 3a and 3b.

The corrosion rate equations, with the appropriate constants, are being used in the predictive corrosion computer program. When a specific Air Force Base is called out, the program automatically uses the equation which corresponds to the environmental conditions at that base.

4.2 Coating Degradation

The external surfaces of most Air Force planes are completely painted. Except in the case of mechanical damage, the time required for fuselage and wing structure to corrode is the coating degradation time plus the corrosion time.

Again, the literature search did not disclose data for the deterioration of Air Force coating systems in all the types of environments which are being considered in this program. The best analysis of the complex factors involved is in Dr. Summitt's report.(1) His basic coating degradation algorithm is shown in Figure 4. The environmental factors

Environmental Constants for Corrosion Equations

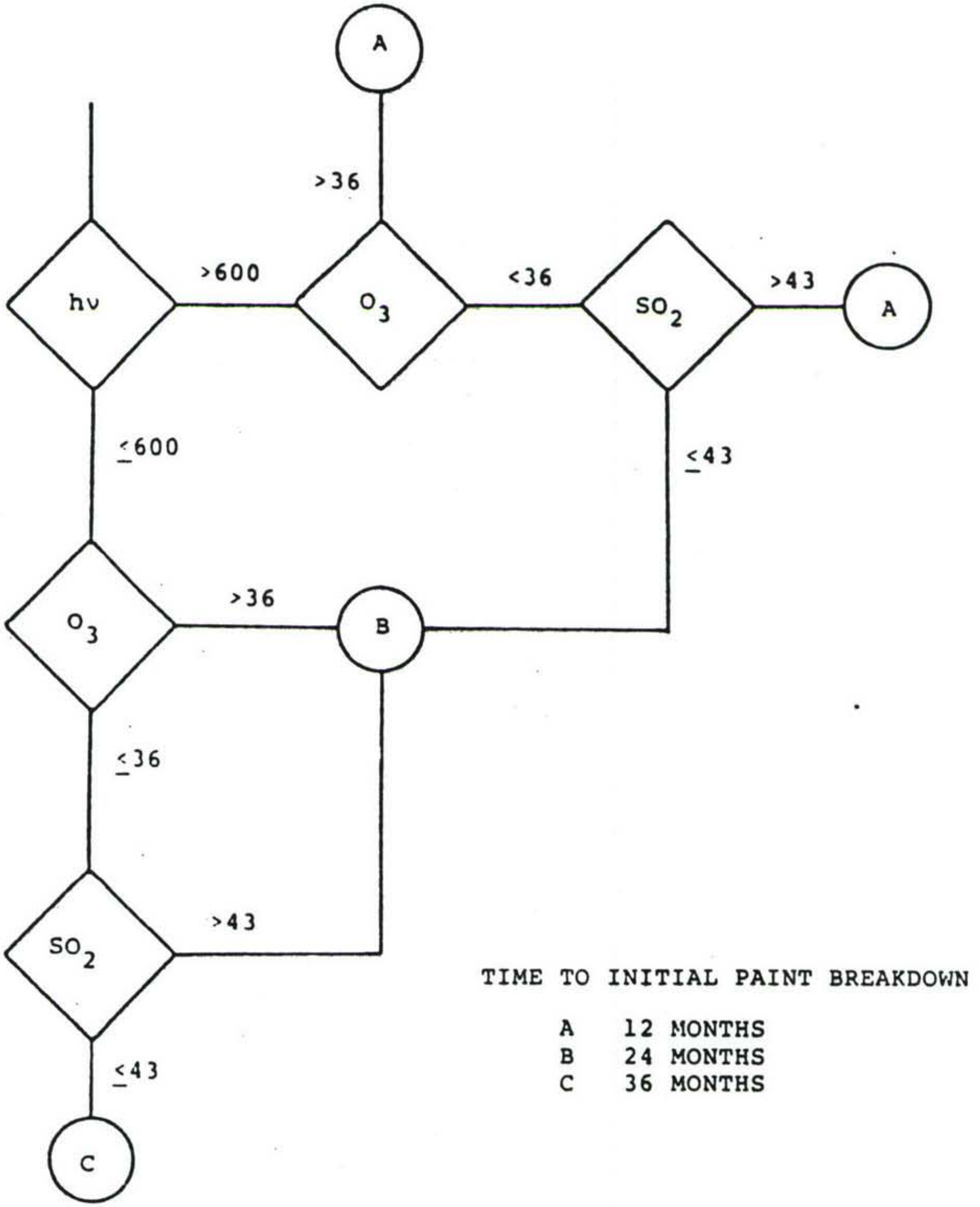
Alloy	Corrosion Index							
	Mild		Moderate		Severe		Very Severe	
	A	B	A	B	A	B	A	B
7075-T6 Al	3.0E-5	0.46	2.95E-5	0.59	2.9E-5	0.72	1.78E-3	0.12
2024-T3 (CLAD)	3.6E-6	0.70	4.9E-6	0.77	6.3E-6	0.85	1.48E-5	0.70
7079-T6	1.9E-6	0.89	2.05E-6	0.94	2.2E-6	1.00	5.4E-9	2.00
7075-T73	3.0E-5	0.46	3.6E-5	0.50	9.0E-4	0.50	9.3E-4	0.50

Figure 3a.

Environmental Constants for Corrosion Equations (Cont'd)

Alloy	Corrosion Index							
	Mild		Moderate		Severe		Very Severe	
	A	B	A	B	A	B	A	B
AZ31B-H24	4.0E-4	0.77	2.8E-4	0.87	1.6E-4	0.97	1.2E-4	1.30
2024-T3	5.0E-4	0.30	5.3E-3	0.11	1.43E-2	0.05	1.1E-3	0.30
4340 Steel	3.5E-11	2.52	2.6E-8	1.40	4.11E-5	1.00	6.9E-5	1.00
300M Steel	3.5E-11	2.52	6.3E-9	2.00	7.3E-5	1.00	5.7E-4	1.00

Figure 3b.



TIME TO INITIAL PAINT BREAKDOWN

A	12 MONTHS
B	24 MONTHS
C	36 MONTHS

Figure 4. Paint Renewal Algorithm

which cause the breakdown of coating systems are ultraviolet radiation, ozone, and sulfur dioxide. By establishing threshold values for the intensity of ultraviolet, and concentrations of ozone and sulfur dioxide, this algorithm enables bases to be rated for their effect on paint systems. An "A" rating represents high values of UV and atmospheric contaminants, a "B" rating intermediate values, and a "C" rating low values.

This algorithm provides a good basis for determining coating degradation rates and was modified to reflect Lockheed experience with the service life of various coating systems. In the predictive corrosion modeling project, the time to initial breakdown of the coating system is more important than time to repaint because, by the time a paint system has degraded to the point where repainting is desirable, an extensive amount of corrosion damage may have occurred.

It is recommended that a new category of paint maintenance called "Paint Renewal" be introduced. This would be a touchup and repainting of only worn or damaged areas. For the paint renewal maintenance, A, B, and C in the algorithm will represent 12, 24 and 36 months. At every fourth paint renewal interval, the aircraft should be completely stripped and repainted.

4.3 Predictive Corrosion Modeling Computer Program

4.3.1 Summary of Logic

The objective of the computer program is to provide a fully integrated method of predicting crack growth, corrosion damage, or coating degradation rates for C-5 aircraft in a variety of environments. The program is designed so it may be integrated with the current structural integrity and tracking programs with a minimum of manhours and expense.

The flow diagrams for the VAX-11 FORTRAN computer program are illustrated in Figures 5 and 6. The program is designed to (a) calculate the amount or degree of corrosion or coating degradation which occurs on C-5 aircraft

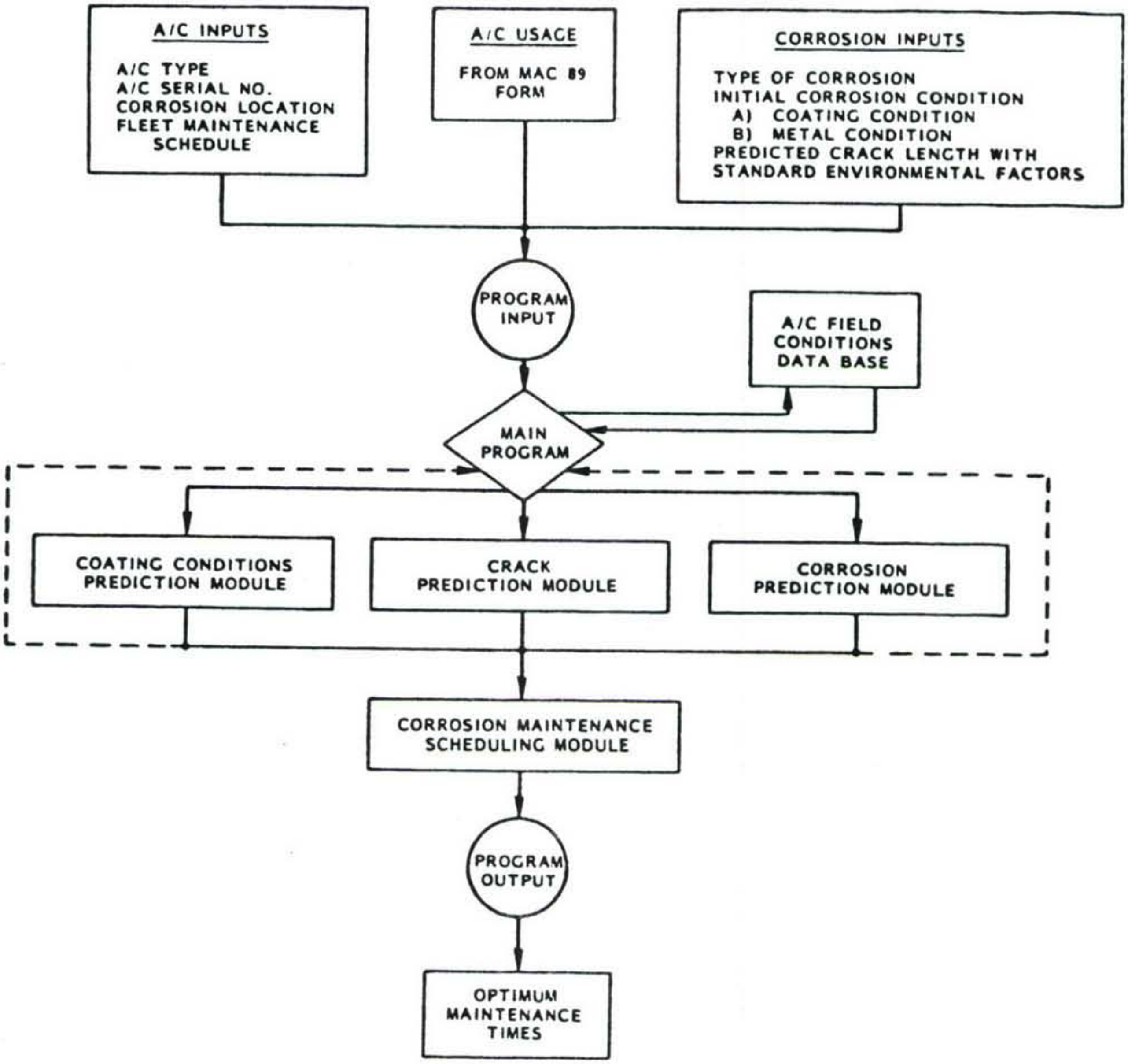


Figure 5. Flow Diagram for FORTRAN Computer Program.

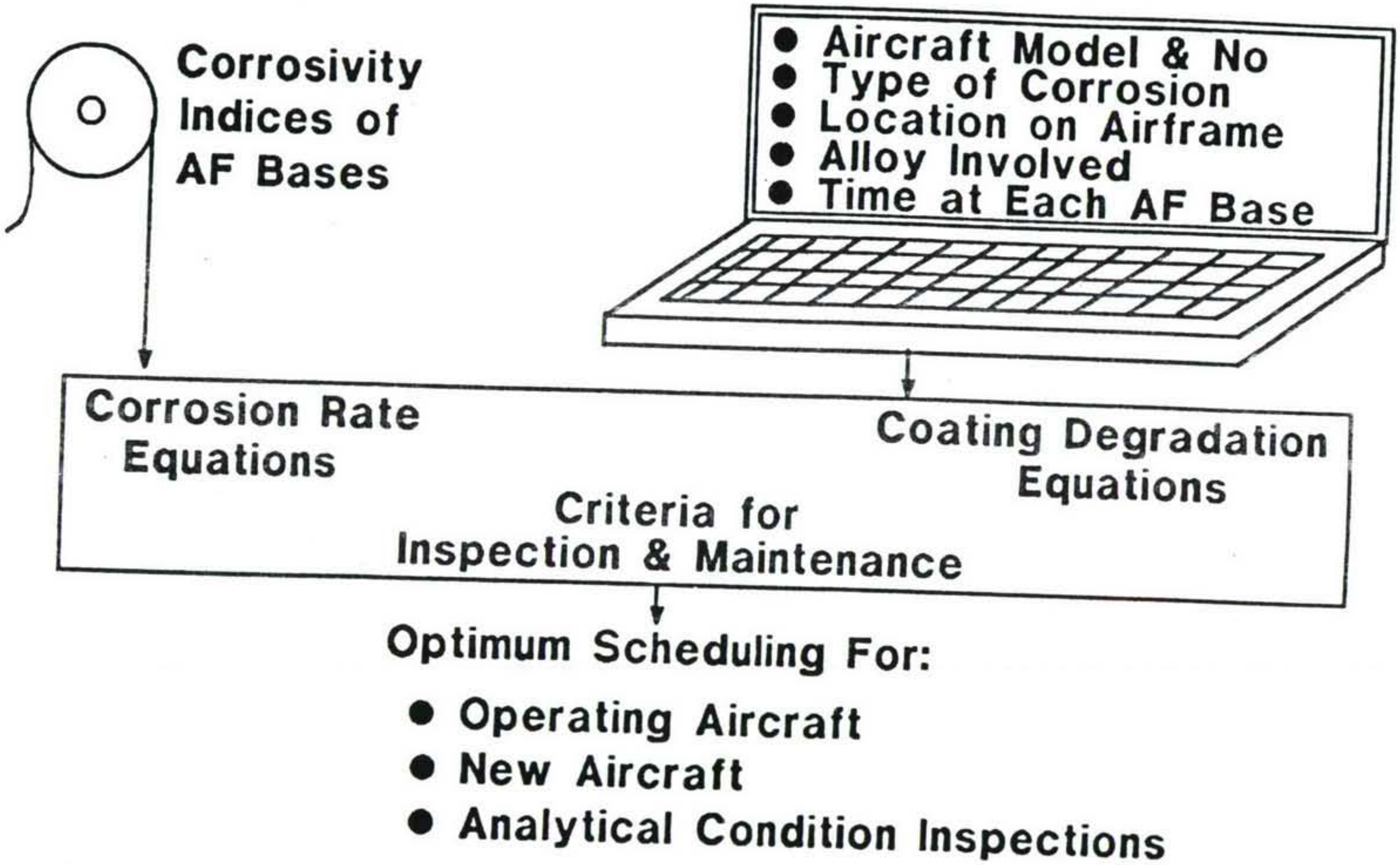


Figure 6. Predictive Corrosion Model.

operating in a variety of environments, (b) convert the data obtained into optimum time to next inspection, and (c) select specific scheduled maintenance times for doing the corrosion repair or paint renewal.

In its present form, the program is to be used in conjunction with the C-5 and C-141 crack monitoring programs and the C-5 and C-141 usage tapes which, for each aircraft, give a historical record of the bases of operation, the flight dates, flight durations, and the total mission hours.

Common inputs to the program are in the type of aircraft (C-5 or C-141), the tail number, the point on the aircraft which is being analyzed for corrosion or coating degradation, and the fleet maintenance schedule.

Other inputs required are the aircraft usage history from the usage tapes and information relating to protective coating system, the alloy involved, and the crack lengths predicted by the C-5 or C-141 crack programs.

The computer program contains modules for predicting fatigue and stress corrosion crack growth, for calculating the depth of corrosion of exposed metal, and for determining the degree of degradation of paint systems.

4.3.2 Crack Growth Prediction Module

Crack growth due to fatigue corrosion in flight and stress corrosion during ground standing are estimated in separate submodules. The module is not "stand alone" in that it relies on input from the C-5 or C-141 crack growth prediction programs, which calculate crack growth of an assumed inherent flaw due to fatigue corrosion for several specific analysis locations on a flight-by-flight basis. The crack growth prediction module adjusts that crack growth according to the environments at the Air Force bases from which the aircraft departs.

Inputs to the crack growth prediction module include the initial crack length, the bases transiented by the aircraft, and the number of flights, duration of each flight, 100 percent humidity crack growth prediction for each flight, and ground time between each flight for each base. Additional inputs include the crack location and the type of material.

Continental United States Air Force bases, including those in Alaska and Hawaii, have been classified into four corrosivity groups depending primarily on average humidity and salt water concentration. The C-5 and C-141 Crack Growth Prediction Programs estimate crack lengths based on 90 to 100 percent relative humidity conditions. The fatigue corrosion prediction submodule of the corrosion prediction program applies a correction factor to that crack growth prediction and adds the adjusted crack growth to the original crack length. In addition, the stress corrosion prediction submodule calculates any stress corrosion cracking that may occur during ground standing between flights and adds that value to the post-flight crack length before the next flight.

4.3.3 Corrosion Prediction Module

The corrosion module contains data on the corrosion rates of aircraft alloys in the environments which exist at Air Force bases. These rates were determined from the equations disclosed by literature search and from corrosion tests with aircraft alloys in simulated and actual environments. Once the specific alloy and the bases of operation of the aircraft are specified, the module automatically selects the proper equations. The corrosion module predicts the time required for aircraft alloys to corrode to a depth of 3 mils (0.0762 mm) in various Air Force base environments.

The corrosion rate equations which are being used in the program are those discussed in Section 4.1. These have been selected from the literature search or developed from experimental data.

From the Corrosivity Index ratings of the Air Force bases, actual corrosion data obtained by exposing aircraft alloys at selected bases, and the results of the potentiostatic polarization tests, the corrosion rate for specific alloys at any of the Air Force bases can be calculated. In the computer program, each base is assigned a corrosion rate for each alloy. When a point on an aircraft is being analyzed, the proper amount of corrosion damage is automatically allocated for the time at each base.

4.3.4 Coating Degradation Module

Primary inputs to the coating degradation prediction module include the specific coating system and the approximate coating life remaining in a moderately severe environment at the start of the simulation, the Air Force bases at which the aircraft has been stationed, and the time spent at each base. The program estimates the coating life "used" at each base. This estimate is calculated at each base, and is subtracted from the coating life remaining to result in the recommended time to the next Intensive Paint Renewal (through cleaning and touchup of degraded areas). The approximate time remaining before the next complete repaint is also calculated by assuming that a complete repaint shall be required every four Intensive Paint Renewals.

4.3.5 Crack Monitoring Points

The C-5 crack monitoring program now in use at Oklahoma City AFB tracks 46 theoretical cracks. Figure 7 shows the location of points on the wing, fuselage and tail assembly which have high stresses. A structural analysis for each of these points has been made and is available for use in this program. Seven of these points have been selected for use in the initial predictive corrosion modeling computer program. The baseline crack growth curve data for the points are tabulated in Appendix A.

The selected points are:

1.	6290SS1	Spanwise Splice - Lower Wing Surface
2.	4250SS1	Spanwise Splice - Lower Wing Surface

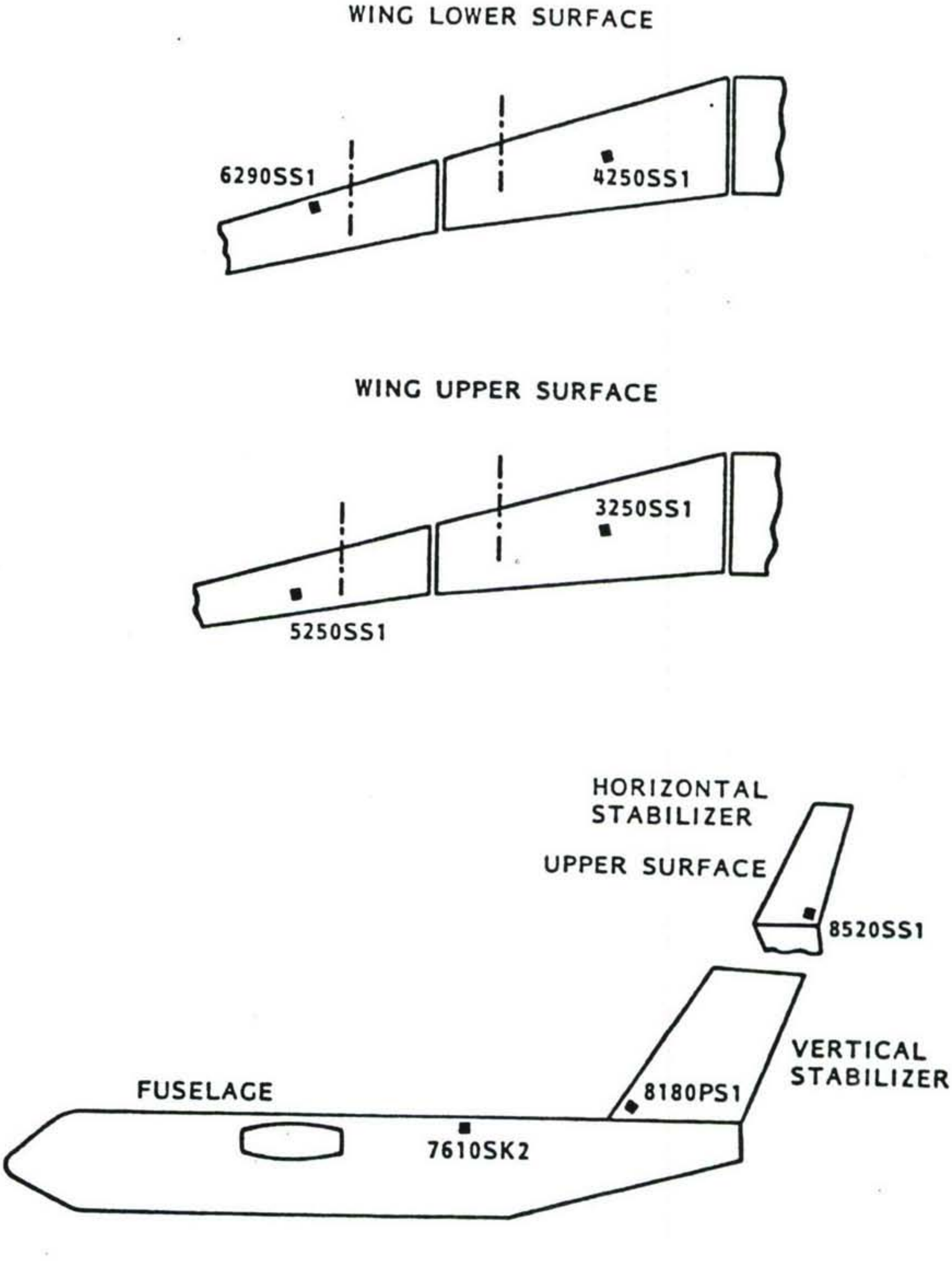


Figure 7 . Location of Crack Monitoring Points on C-5A Aircraft.

3. 5250SS1 Spanwise Splice - Upper Wing Surface
4. 3250SS1 Spanwise Splice - Upper Wing Surface
5. 7610SK2 Skin - Upper Fuselage
6. 8180PS1 Panel Splice - Vertical Stabilizer
7. 8520SS1 Spanwise Splice - Horizontal Stabilizer, Upper Surface

After the program has been validated by comparing predicted crack lengths with actual cracks, it will be used to track any of the 46 theoretical cracks now being monitored.

The computer program was designed so, with only minor modification, it can be used for any aircraft which already has a crack monitoring program. The C-141, C-130, and B-52 fleets have such programs.

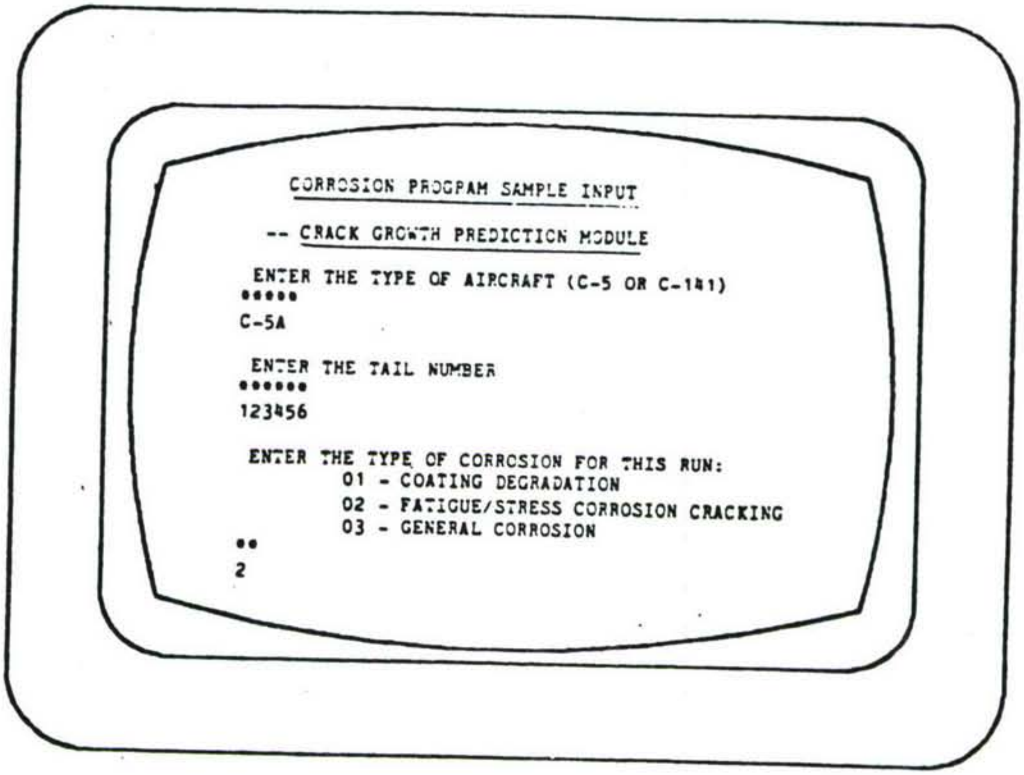
4.3.6 Corrosion Maintenance Scheduling Module

The outputs of the corrosion, coating degradation, and crack growth prediction modules will be input to a corrosion maintenance scheduling module which will compare the upcoming maintenance schedule with the aircraft corrosion condition. The module will determine the best time to perform corrosion control maintenance items based on the aircraft condition and the capabilities of scheduled maintenance actions.

4.3.7 FORTRAN Program Screen Displays

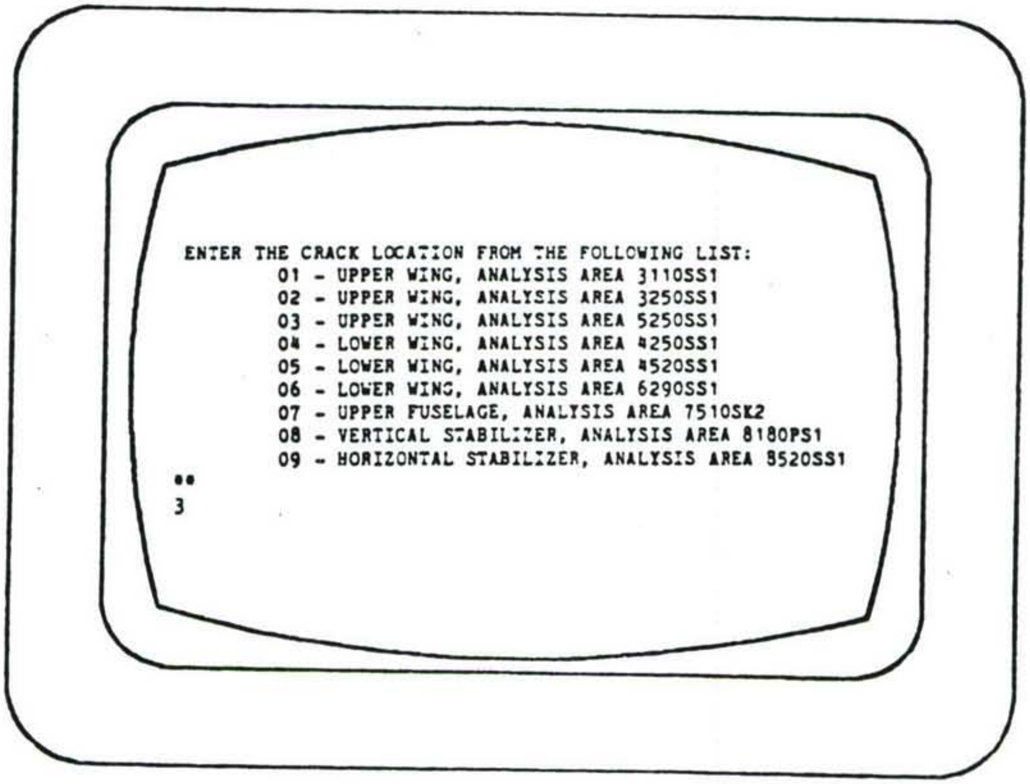
The data and logic developed to date have been integrated into a FORTRAN computer program which contains essential portions of the final program. The following section is a reproduction of the menu driven screens for data entry and display.

CRACK GROWTH PREDICTION MODULE
SCREENS



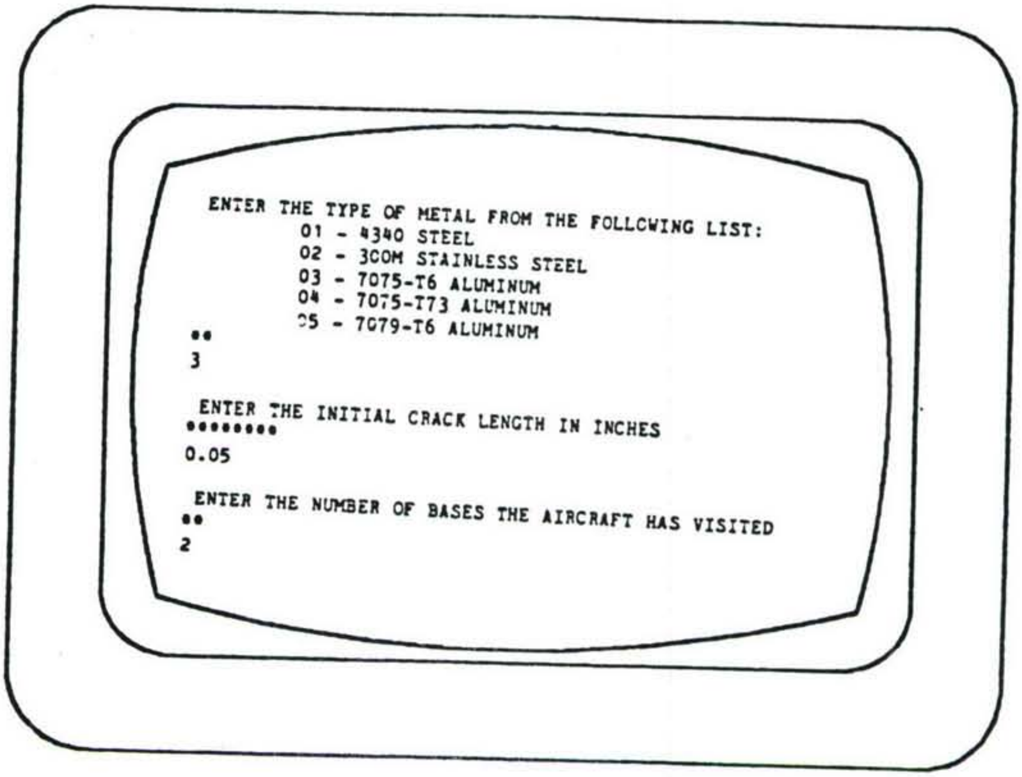
```
     CORROSION PROGRAM SAMPLE INPUT

   -- CRACK GROWTH PREDICTION MODULE

 ENTER THE TYPE OF AIRCRAFT (C-5 OR C-141)
•••••
C-5A

 ENTER THE TAIL NUMBER
••••••
123456

 ENTER THE TYPE OF CORROSION FOR THIS RUN:
        01 - COATING DEGRADATION
        02 - FATIGUE/STRESS CORROSION CRACKING
        03 - GENERAL CORROSION
••
2
```

(a)



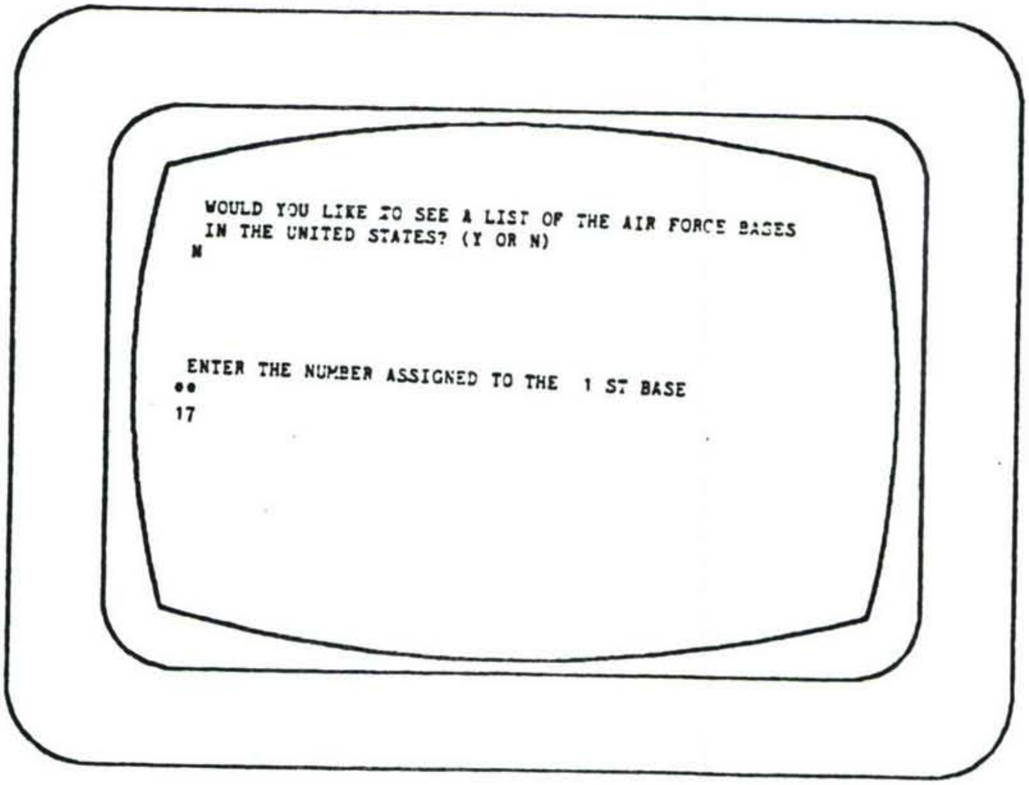
```
ENTER THE CRACK LOCATION FROM THE FOLLOWING LIST:
        01 - UPPER WING, ANALYSIS AREA 3110SS1
        02 - UPPER WING, ANALYSIS AREA 3250SS1
        03 - UPPER WING, ANALYSIS AREA 5250SS1
        04 - LOWER WING, ANALYSIS AREA 4250SS1
        05 - LOWER WING, ANALYSIS AREA 4520SS1
        06 - LOWER WING, ANALYSIS AREA 6290SS1
        07 - UPPER FUSELAGE, ANALYSIS AREA 7510SK2
        08 - VERTICAL STABILIZER, ANALYSIS AREA 8180PS1
        09 - HORIZONTAL STABILIZER, ANALYSIS AREA 8520SS1
••
3
```

(b)



```
 ENTER THE TYPE OF METAL FROM THE FOLLCWING LIST:
          01 - 4340 STEEL
          02 - 3COM STAINLESS STEEL
          03 - 7075-T6 ALUMINUM
          04 - 7075-T73 ALUMINUM
          05 - 7079-T6 ALUMINUM
••
3

 ENTER THE INITIAL CRACK LENGTH IN INCHES
••••••••
0.05

 ENTER THE NUMBER OF BASES THE AIRCRAFT HAS VISITED
••
2
```

(c)



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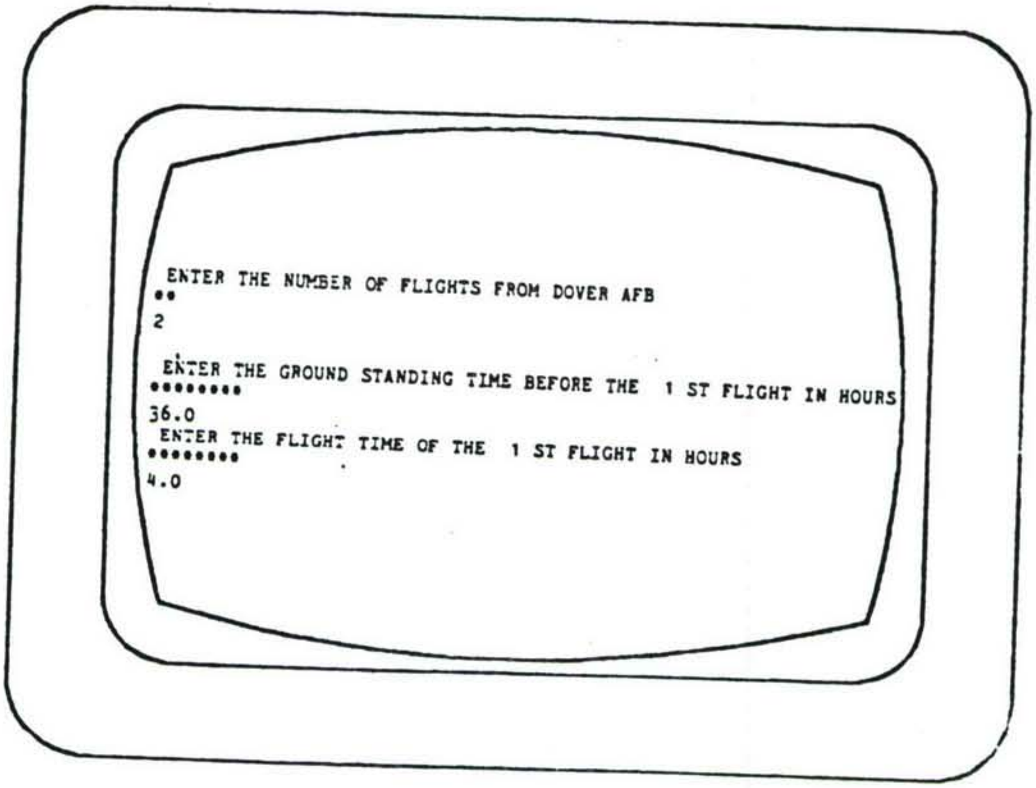
  WOULD YOU LIKE TO SEE A LIST OF THE AIR FORCE BASES
  IN THE UNITED STATES? (Y OR N)
 N


 ENTER THE NUMBER ASSIGNED TO THE  1 ST BASE
••
17
```

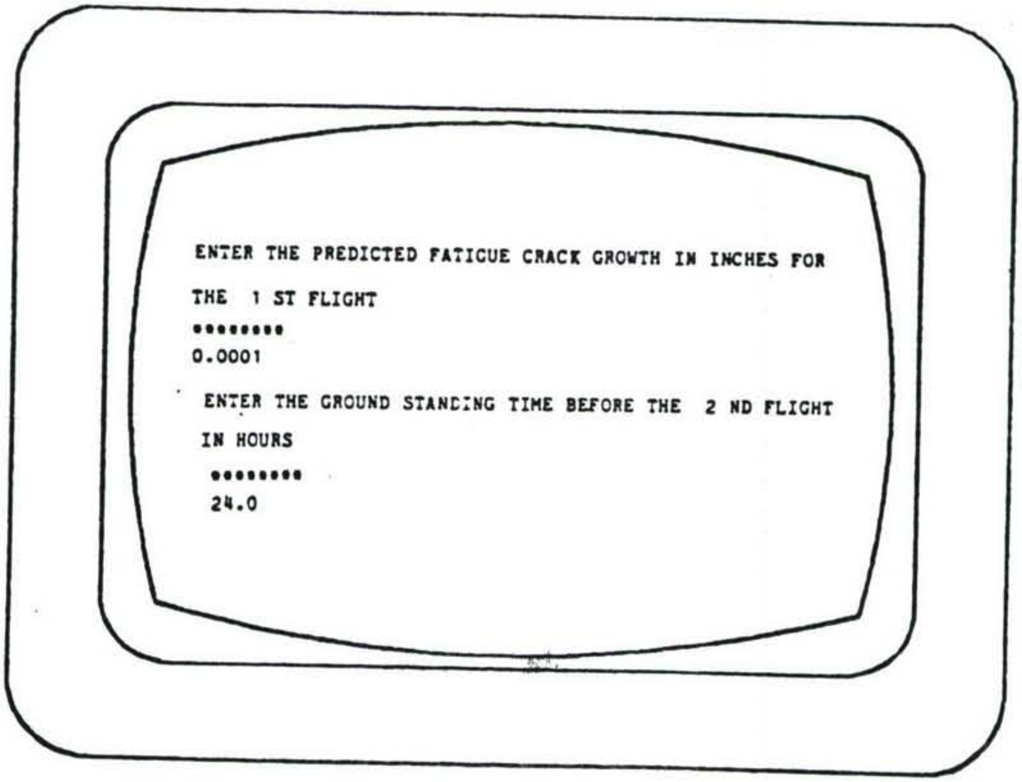
(d)



```
ENTER THE NUMBER OF FLIGHTS FROM DOVER AFB
••
2

ENTER THE GROUND STANDING TIME BEFORE THE  1 ST FLIGHT IN HOURS
••••••••
36.0
ENTER THE FLIGHT TIME OF THE  1 ST FLIGHT IN HOURS
••••••••
4.0
```

(e)



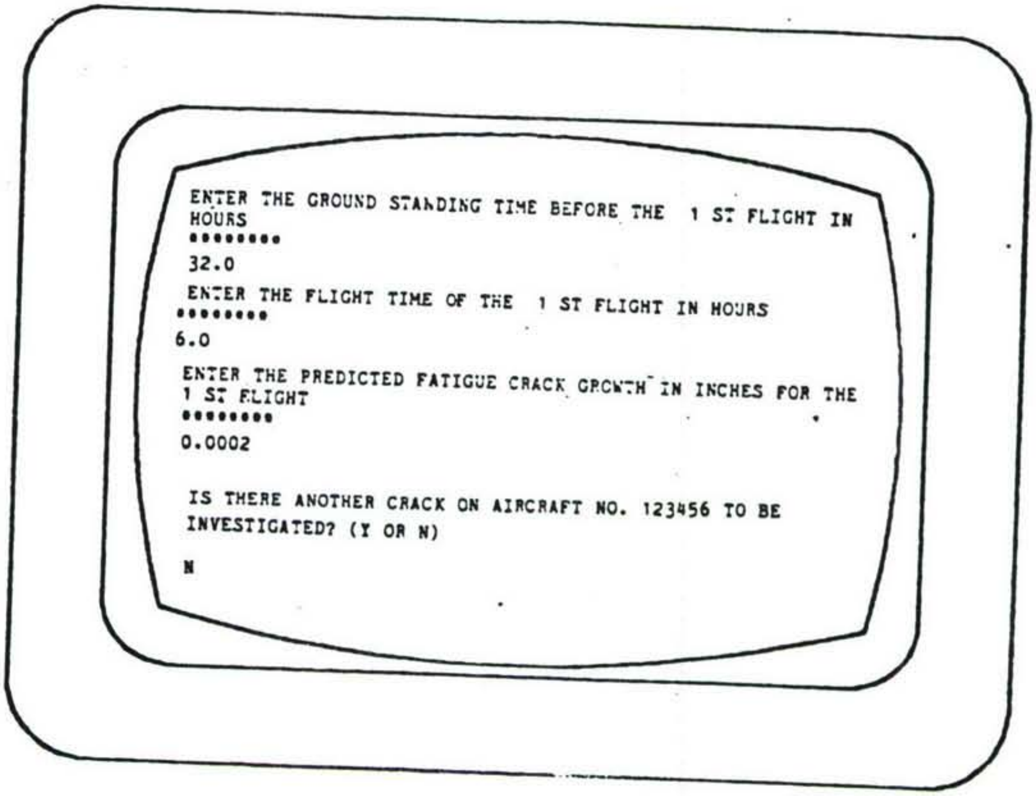
```
ENTER THE PREDICTED FATIGUE CRACK GROWTH IN INCHES FOR

THE  1 ST FLIGHT
••••••••
0.0001

ENTER THE GROUND STANDING TIME BEFORE THE  2 ND FLIGHT

IN HOURS
••••••••
24.0
```

(f)

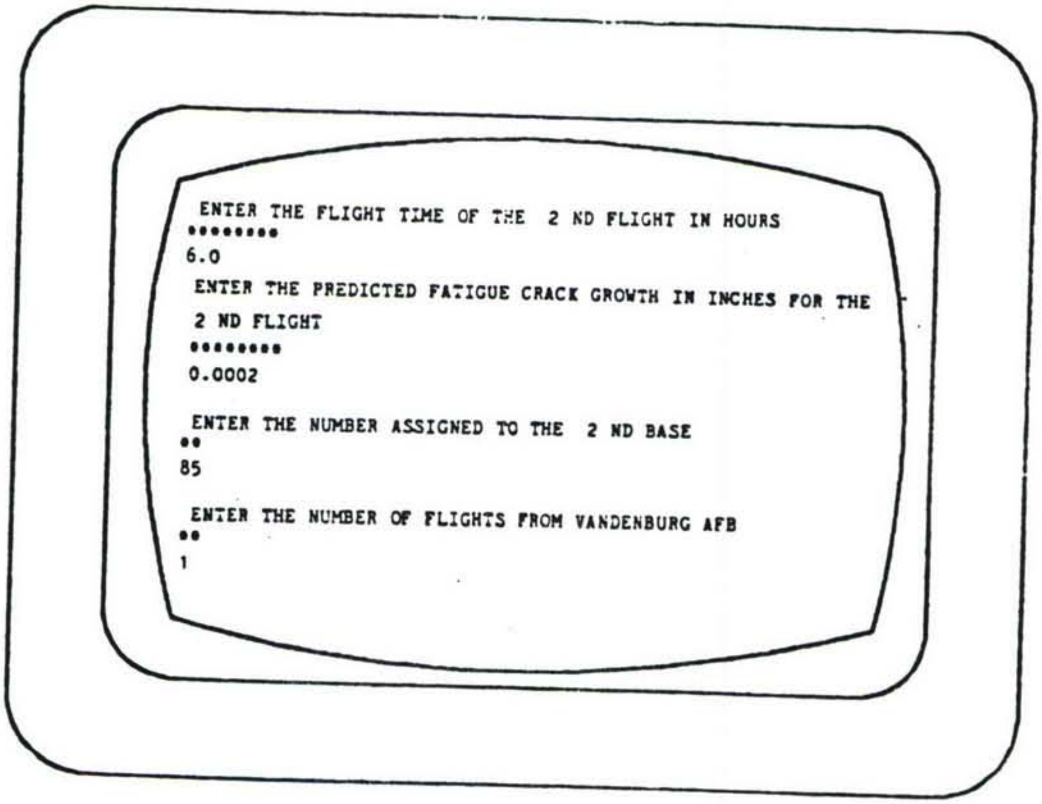


```
ENTER THE GROUND STANDING TIME BEFORE THE  1 ST FLIGHT IN
HOURS
••••••••
32.0
ENTER THE FLIGHT TIME OF THE  1 ST FLIGHT IN HOURS
••••••••
6.0
ENTER THE PREDICTED FATIGUE CRACK GROWTH IN INCHES FOR THE
1 ST FLIGHT
••••••••
0.0002


IS THERE ANOTHER CRACK ON AIRCRAFT NO. 123456 TO BE
INVESTIGATED? (Y OR N)

N
```

(g)

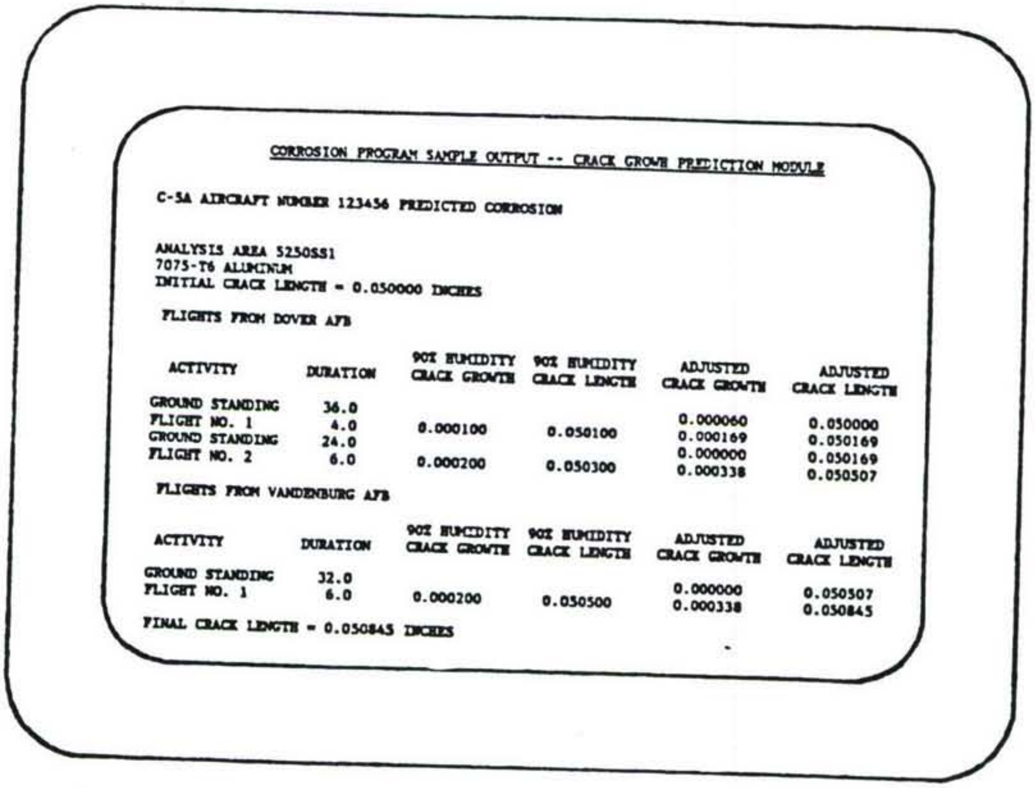


```
ENTER THE FLIGHT TIME OF THE  2 ND FLIGHT IN HOURS
••••••••
6.0
ENTER THE PREDICTED FATIGUE CRACK GROWTH IN INCHES FOR THE
2 ND FLIGHT
••••••••
0.0002

ENTER THE NUMBER ASSIGNED TO THE  2 ND BASE
••
85

ENTER THE NUMBER OF FLIGHTS FROM VANDENBURG AFB
••
1
```

(h)



```
          CORROSION PROGRAM SAMPLE OUTPUT -- CRACK GROWH PREDICTION MODULE

C-5A AIRCRAFT NUMBER 123456 PREDICTED CORROSION

ANALYSIS AREA 5250SS1
7075-T6 ALUMINUM
INITIAL CRACK LENGTH = 0.050000 INCHES

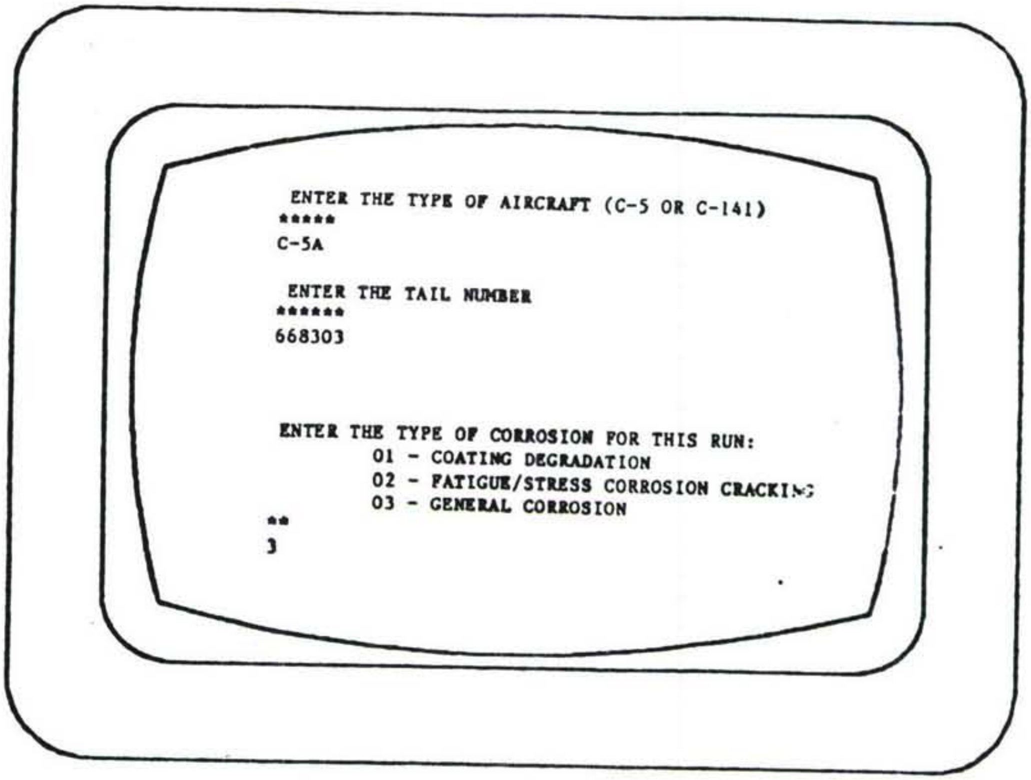
 FLIGHTS FROM DOVER AFB

                                90% HUMIDITY  90% HUMIDITY    ADJUSTED       ADJUSTED
  ACTIVITY         DURATION     CRACK GROWTH  CRACK LENGTH  CRACK GROWTH   CRACK LENGTH
 GROUND STANDING     36.0
 FLIGHT NO. 1         4.0        0.000100      0.050100      0.000060       0.050000
 GROUND STANDING     24.0                                    0.000169       0.050169
 FLIGHT NO. 2         6.0        0.000200      0.050300      0.000000       0.050169
                                                             0.000338       0.050507
 FLIGHTS FROM VANDENBURG AFB

                                90% HUMIDITY  90% HUMIDITY    ADJUSTED       ADJUSTED
  ACTIVITY         DURATION     CRACK GROWTH  CRACK LENGTH  CRACK GROWTH   CRACK LENGTH
 GROUND STANDING     32.0
 FLIGHT NO. 1         6.0        0.000200      0.050500      0.000000       0.050507
                                                             0.000338       0.050845
FINAL CRACK LENGTH = 0.050845 INCHES
```

(i)

CORROSION PREDICTION MODULE
SCREENS

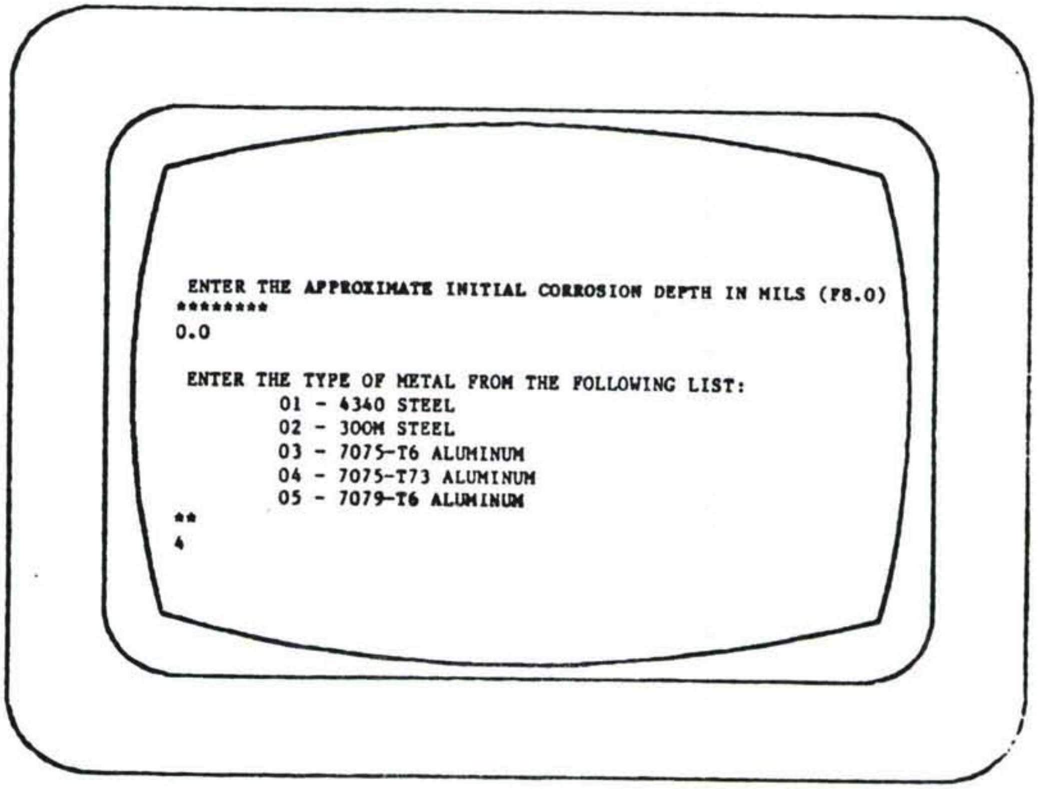


```
 ENTER THE TYPE OF AIRCRAFT (C-5 OR C-141)
*****
C-5A

 ENTER THE TAIL NUMBER
******
668303


 ENTER THE TYPE OF CORROSION FOR THIS RUN:
         01 - COATING DEGRADATION
         02 - FATIGUE/STRESS CORROSION CRACKING
         03 - GENERAL CORROSION
**
3
```

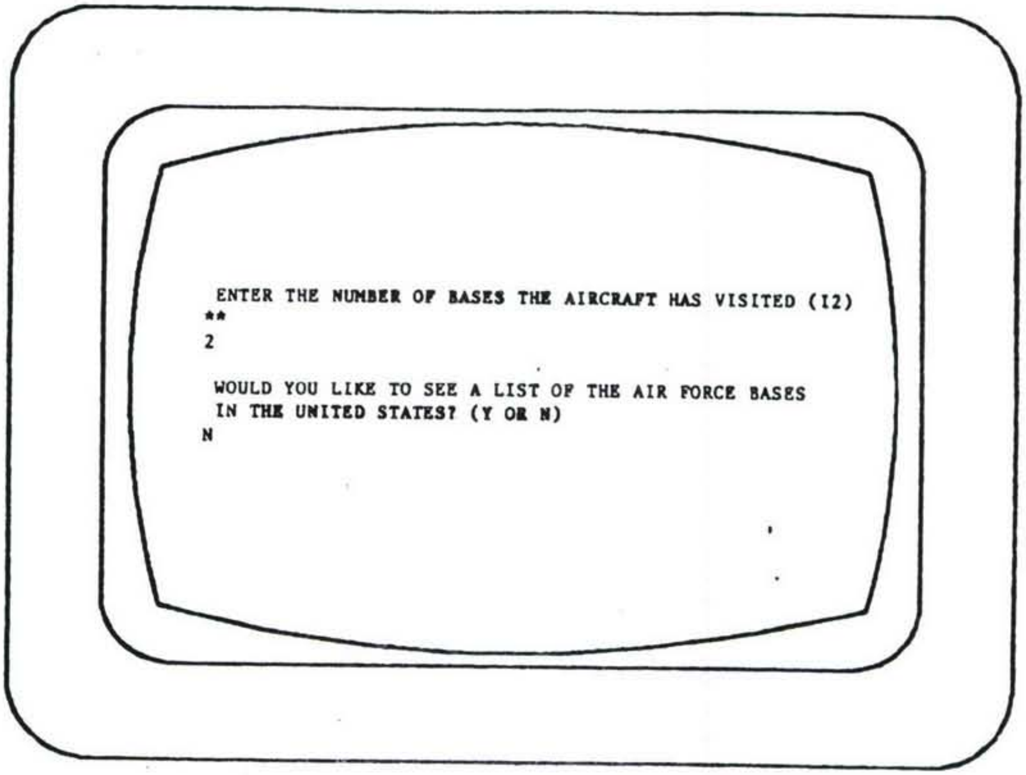
(a)



```
 ENTER THE APPROXIMATE INITIAL CORROSION DEPTH IN MILS (F8.0)
********
0.0

 ENTER THE TYPE OF METAL FROM THE FOLLOWING LIST:
         01 - 4340 STEEL
         02 - 300M STEEL
         03 - 7075-T6 ALUMINUM
         04 - 7075-T73 ALUMINUM
         05 - 7079-T6 ALUMINUM
**
4
```

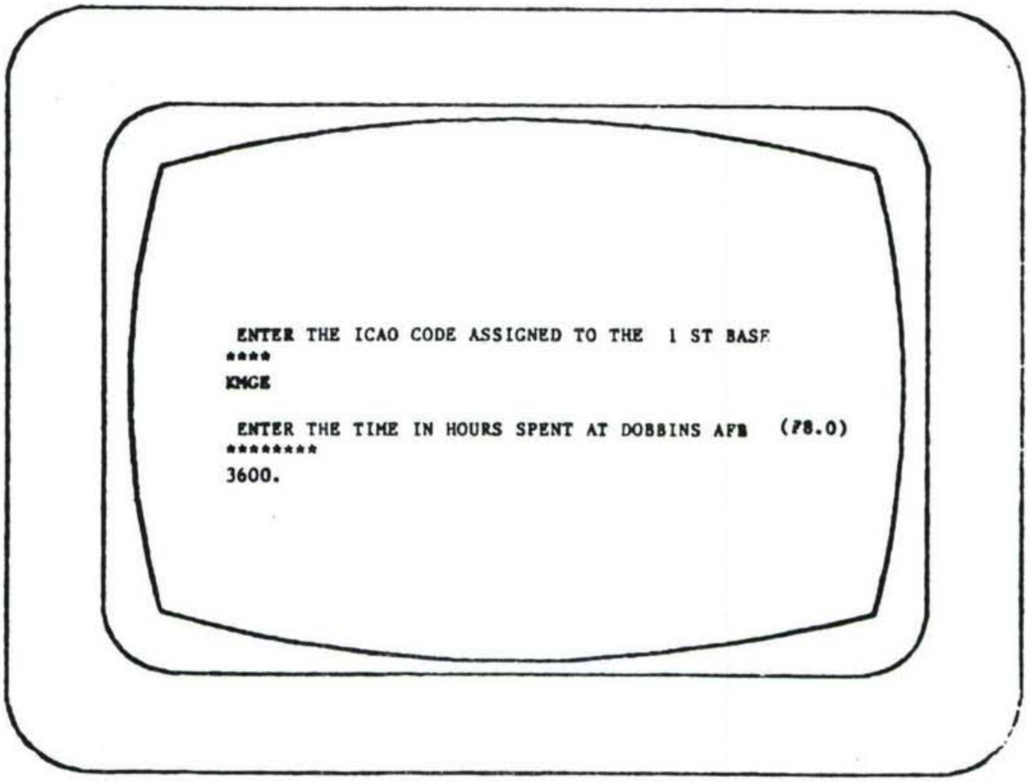
(b)



```
 ENTER THE NUMBER OF BASES THE AIRCRAFT HAS VISITED (I2)
**
2

 WOULD YOU LIKE TO SEE A LIST OF THE AIR FORCE BASES
 IN THE UNITED STATES? (Y OR N)
N
```

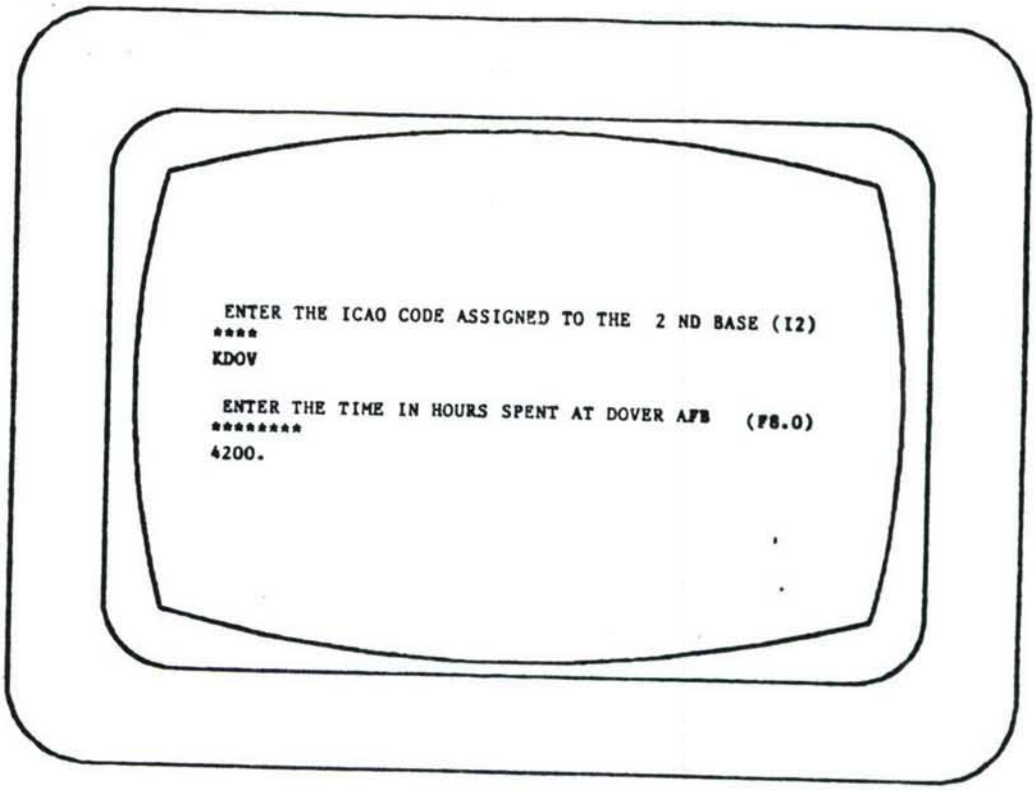
(c)



```
 ENTER THE ICAO CODE ASSIGNED TO THE  1 ST BASE
****
KMGE

 ENTER THE TIME IN HOURS SPENT AT DOBBINS AFB   (F8.0)
********
3600.
```

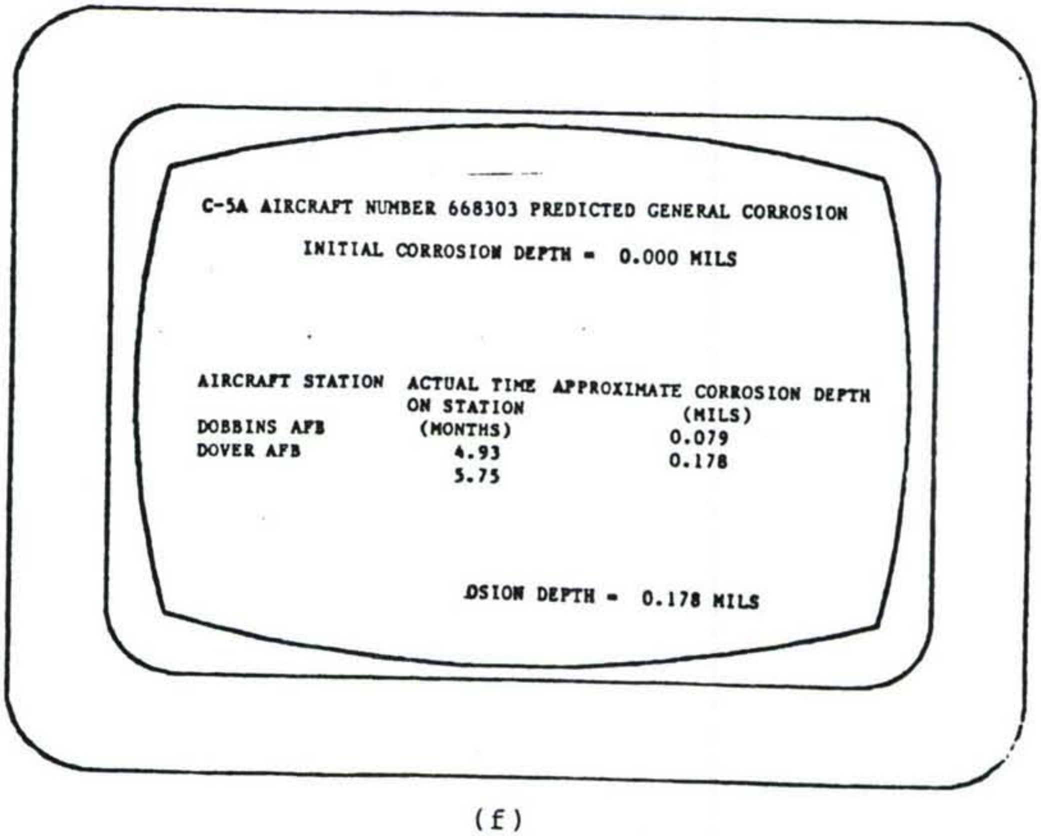
(d)



```
 ENTER THE ICAO CODE ASSIGNED TO THE  2 ND BASE (I2)
****
KDOV

 ENTER THE TIME IN HOURS SPENT AT DOVER AFB   (F8.0)
********
4200.
```

(e)



```
C-5A AIRCRAFT NUMBER 668303 PREDICTED GENERAL CORROSION
        INITIAL CORROSION DEPTH =  0.000 MILS

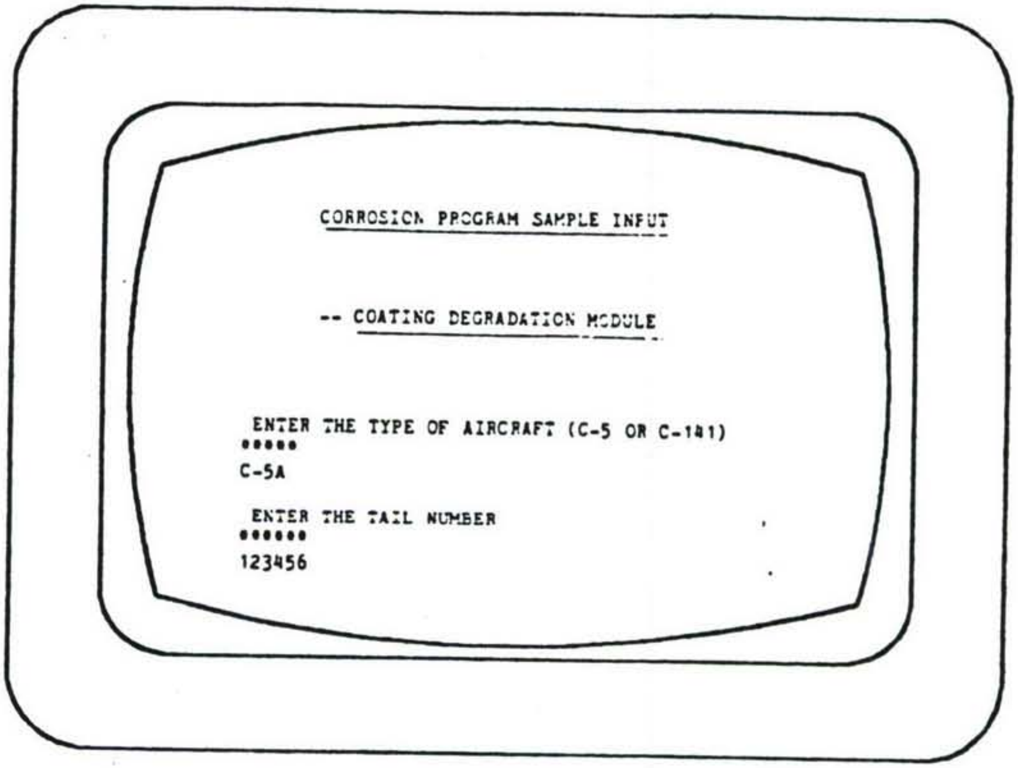

AIRCRAFT STATION  ACTUAL TIME APPROXIMATE CORROSION DEPTH
                  ON STATION              (MILS)
DOBBINS AFB        (MONTHS)              0.079
DOVER AFB            4.93                0.178
                     5.75



                   DSION DEPTH =  0.178 MILS
```

(f)

COATING DEGRADATION MODULE
SCREENS



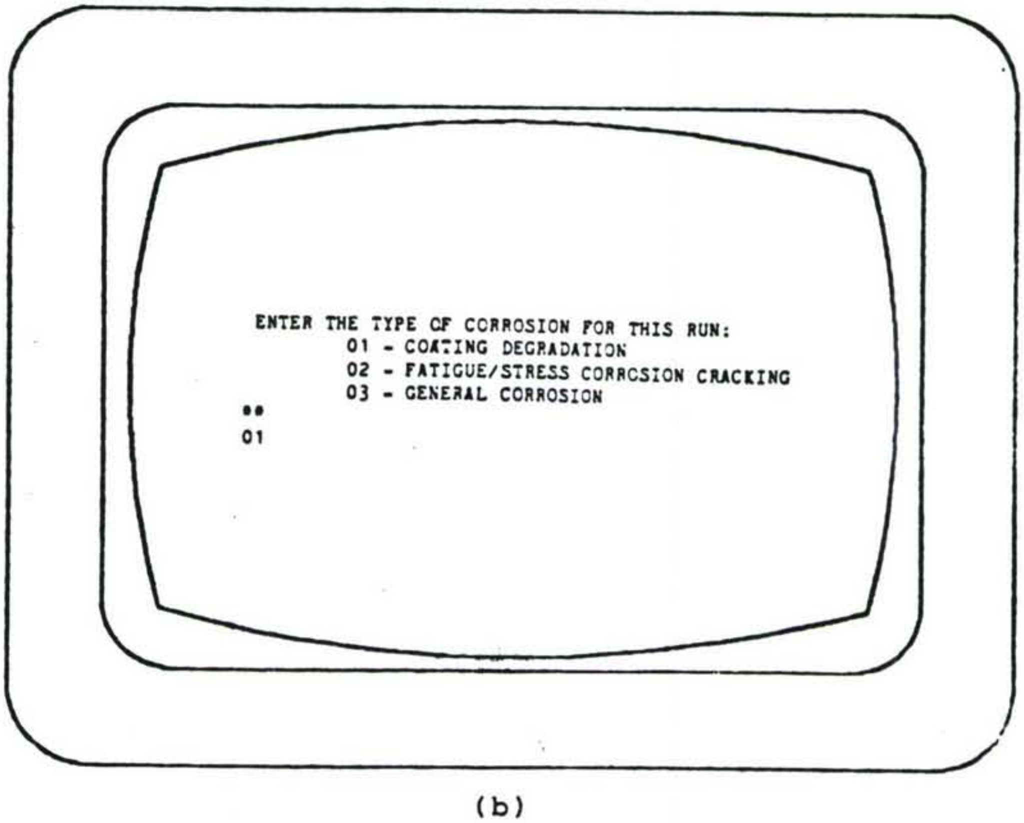
```
CORROSION PROGRAM SAMPLE INPUT

-- COATING DEGRADATION MODULE

 ENTER THE TYPE OF AIRCRAFT (C-5 OR C-141)
*****
C-5A

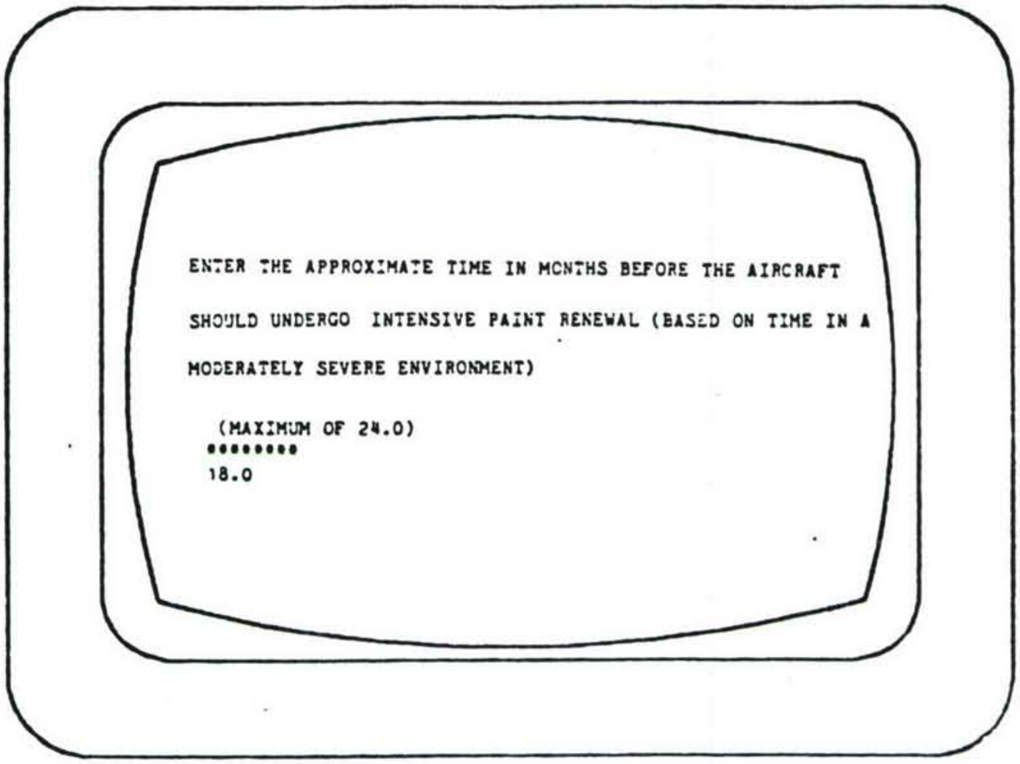
 ENTER THE TAIL NUMBER
******
123456
```

(a)



```
ENTER THE TYPE OF CORROSION FOR THIS RUN:
        01 - COATING DEGRADATION
        02 - FATIGUE/STRESS CORROSION CRACKING
        03 - GENERAL CORROSION
**
01
```

(b)



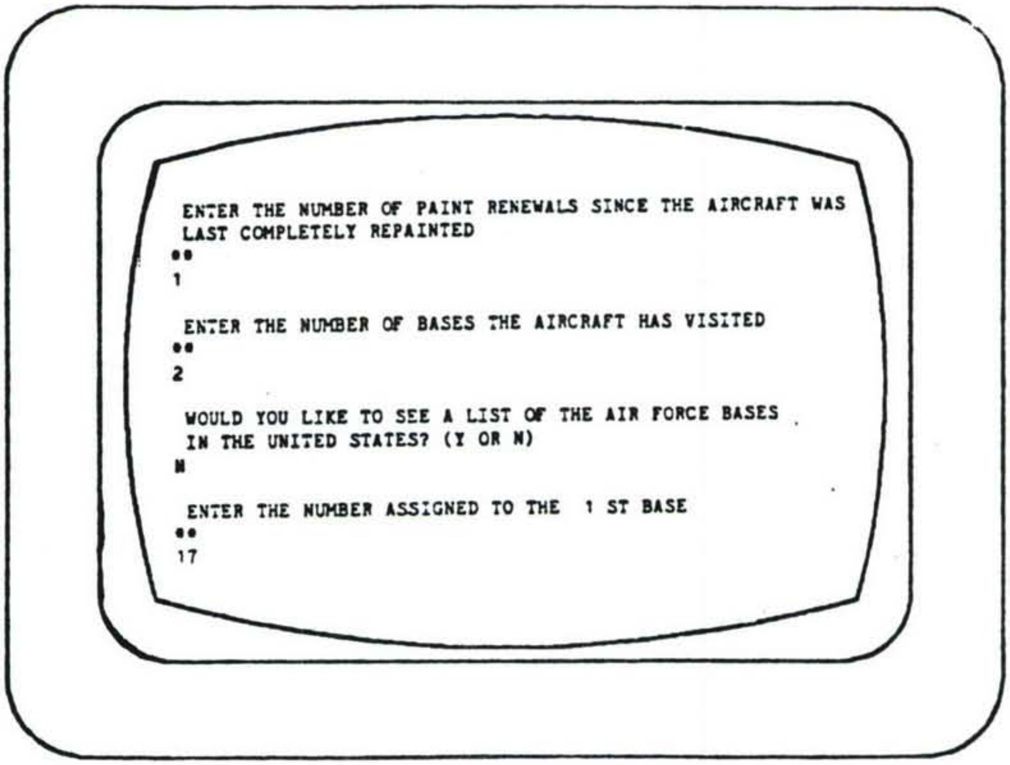
```
ENTER THE APPROXIMATE TIME IN MONTHS BEFORE THE AIRCRAFT

SHOULD UNDERGO  INTENSIVE PAINT RENEWAL (BASED ON TIME IN A

MODERATELY SEVERE ENVIRONMENT)

  (MAXIMUM OF 24.0)
 ********
 18.0
```

(c)



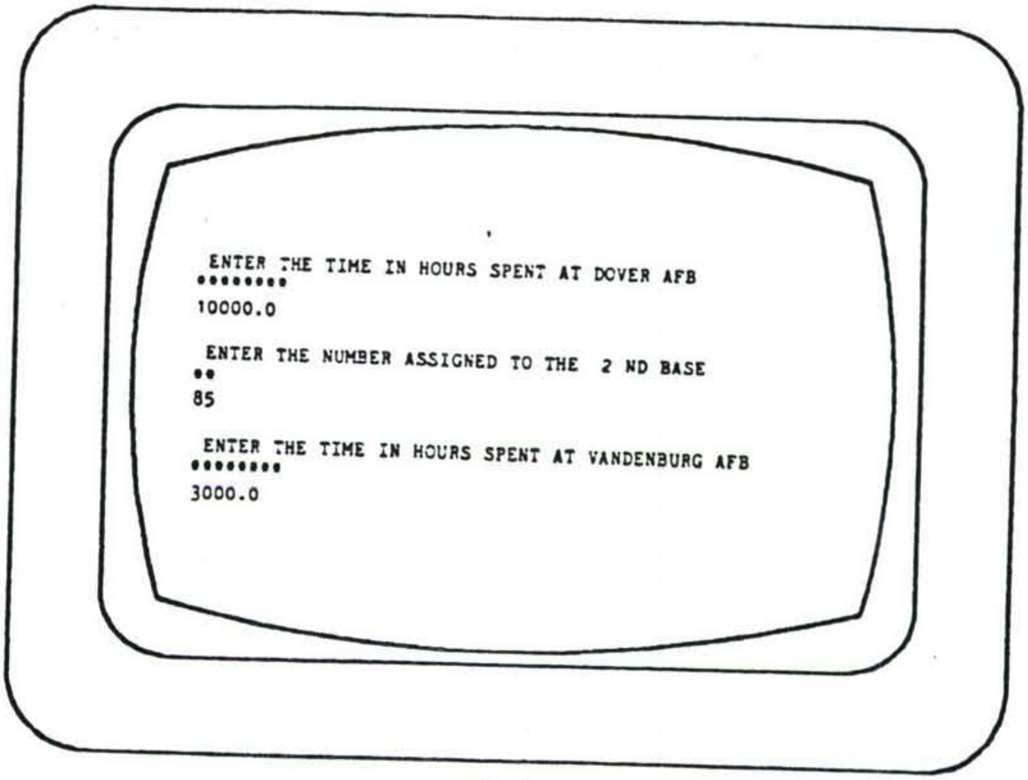
```
 ENTER THE NUMBER OF PAINT RENEWALS SINCE THE AIRCRAFT WAS
 LAST COMPLETELY REPAINTED
**
1

 ENTER THE NUMBER OF BASES THE AIRCRAFT HAS VISITED
**
2

 WOULD YOU LIKE TO SEE A LIST OF THE AIR FORCE BASES
 IN THE UNITED STATES? (Y OR N)
N

 ENTER THE NUMBER ASSIGNED TO THE  1 ST BASE
**
17
```

(d)

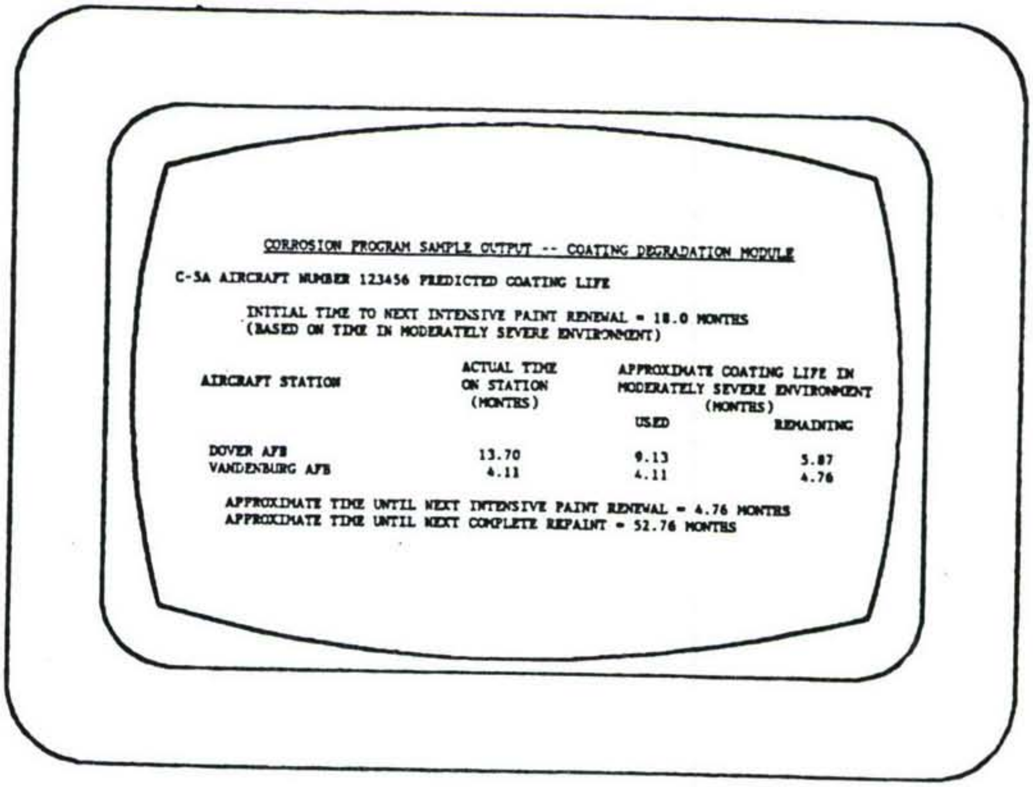


```
 ENTER THE TIME IN HOURS SPENT AT DOVER AFB
********
10000.0

 ENTER THE NUMBER ASSIGNED TO THE  2 ND BASE
**
85

 ENTER THE TIME IN HOURS SPENT AT VANDENBURG AFB
********
3000.0
```

(e)



```
          CORROSION PROGRAM SAMPLE OUTPUT -- COATING DEGRADATION MODULE
C-5A AIRCRAFT NUMBER 123456 PREDICTED COATING LIFE

     INITIAL TIME TO NEXT INTENSIVE PAINT RENEWAL = 18.0 MONTHS
     (BASED ON TIME IN MODERATELY SEVERE ENVIRONMENT)

  AIRCRAFT STATION                ACTUAL TIME     APPROXIMATE COATING LIFE IN
                                  ON STATION      MODERATELY SEVERE ENVIRONMENT
                                   (MONTHS)                 (MONTHS)
                                                    USED              REMAINING

   DOVER AFB                        13.70           9.13                5.87
   VANDENBURG AFB                    4.11           4.11                4.76

    APPROXIMATE TIME UNTIL NEXT INTENSIVE PAINT RENEWAL = 4.76 MONTHS
    APPROXIMATE TIME UNTIL NEXT COMPLETE REPAINT = 52.76 MONTHS
```

(f)

4.3.8 Extraction of Flight Mission Data

A FORTRAN computer program has been developed which creates a flight mission profile for the C-5 aircraft. The program reads the historical useage tapes and automatically builds a flight mission profile for the selected aircraft. The program gives the user the option of selecting a single aircraft serial number or a series of aircraft serial numbers. Additionally, the user can specify a time interval for the selected aircraft.

The output product, reproduced in Figure 8, exhibits the aircraft serial number, mission date, take-off base code/name, enroute full stop base code/name, mission flight time, and the ground time spent at each location.

4.3.9 Analytical Condition Inspection (ACI) Scheduling

Analytical Condition Inspections are a systematic disassembly and inspection of selected representative aircraft to locate hidden defects, deteriorating conditions, corrosion, fatigue, overstress and other deficiencies in the aircraft structure or systems. The C-5 and C-141 ACI's are accomplished concurrent with the Programmed Depot Maintenance (PDM) Modification programs at the San Antonio ALC and Warner-Robins ALC facilities respectively. The PDM cycles for the two aircraft are currently accomplished at intervals of 54 months and 48 months respectively. The number of aircraft selected for ACI are determined by using the ACI sample size table in T.O. 00-25-4.

The specific aircraft scheduled for ACI are selected according to the following considerations pertinent to their utilization:

1. Highest cumulative flying hours.

2. Highest total cumulative landings.

```
SERIAL#  DATE OF  MISSION# GROUND TIME  TOICAO TAKE OFF BASE NAME                 FSICAO ENROUTE FULL STOP BASE NAME  FLIGHT DURATION
         FLIGHT            PRIOR TO
                           TAKE OFF
668304   681004      1         .00      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.92
668304   681008      2       97.75      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.18
668304   681008      2         .22      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .33
668304   681008      2         .22      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .23
668304   681020      3      298.57      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .78
668304   681020      4        5.57      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .65
668304   681214      5     1322.90      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        2.50
668304   681214      5         .37      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .73
668304   681220      6      150.68      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        3.45
668304   681220      6         .25      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .70
668304   681230      7      240.25      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.70
668304   681230      7         .23      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.45
668304   681230      7         .15      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .23
668304   690108      8      224.15      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.88
668304   690110      9       48.72      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        5.50
668304   690115     10      128.13      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.50
668304   690115     10         .27      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        3.93
668304   690116     11       27.85      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .15
668304   690116     12        4.38      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .58
668304   690204     13      456.93      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        2.77
668304   690205     14       27.30      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        2.88
668304   690207     15       52.03      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .28
668304   690209     16       52.32      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        7.75
668304   690214     17      120.85      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .42
668304   690220     18      149.75      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .92
668304   690225     19      125.40      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        3.43
668304   690225     19         .40      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .55
668304   690226     20       28.27      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.42
668304   690226     20         .23      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        5.27
668304   690524     21     2089.17      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.83
668304   690530     22      149.60      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        5.60
668304   690530     22         .22      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .37
668304   690602     23       73.15      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]        1.58
668304   690604     24       54.92      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KEDW   EDWARDS FTC [CA]                    4.35
668304   690605     25       32.75      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    8.00
668304   690607     26       56.17      KEDW   EDWARDS FTC [CA]                  KMGE   DOBBINS AFB/ATLANTA NAS [GA]        3.87
668304   690609     27       49.98      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .47
668304   690609     27         .25      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KMGE   DOBBINS AFB/ATLANTA NAS [GA]         .77
668304   690609     28        1.92      KMGE   DOBBINS AFB/ATLANTA NAS [GA]      KEDW   EDWARDS FTC [CA]                    4.15
668304   690615     29      153.72      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    4.15
668304   690616     30       27.88      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    6.18
668304   690618     31       49.72      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    6.35
668304   690621     32       82.28      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    8.15
668304   690627     33      144.25      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    1.57
668304   690630     34       82.23      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    5.02
668304   690702     35       56.73      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    8.12
668304   690713     36      267.28      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    2.92
668304   690715     37       59.80      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    8.22
668304   690717     38       56.23      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    4.72
668304   690717     39        3.37      KEDW   EDWARDS FTC [CA]                  KEDW   EDWARDS FTC [CA]                    3.22
1
```

Figure 8. C-5 Flight Mission Profile.

3. Unusual percent of utilization in a given mission profile, i.e., training, long range logistics.

4. Relation of total cumulative flight hours to cumulative full stop landings.

5. Base to which aircraft are assigned.

6. Aircraft age in calendar years.

In general, the criteria for ACI selection are related to severity of service. The Predictive Corrosion Modeling program will give an additional important parameter, the severity of the environments in which an aircraft has operated. The aircraft with the longest theoretical cracks, whose lengths have been corrected for severity of environment, should be the ones which are disassembled and inspected for corrosion, fatigue, and other deficiencies in areas which are not inspected in routine maintenance operations.

5.0 DEMONSTRATION EXAMPLE

The effectiveness of the VAX-11 Predictive Corrosion Modeling computer program was demonstrated by predicting fatigue cracking, general corrosion and coating degradation for C-5A aircraft number 668304 from 10/4/68 to 10/4/69, a 1-year time period which included 61 missions.

5.1 Fatigue Crack Prediction

An initial flaw 0.005 inches in length was assumed at crack monitoring point 3250SS1, a spanwise splice in the upper surface of the wing. The metal involved is 7175-T73 aluminum. Utilizing flight history data from the RIM data base and crack growth data from the C-5A crack monitoring programs, the predictive corrosion modeling program adjusted the crack lengths for the environmental conditions at Dobbins and Edwards Air Force Bases and calculated the recommended time until the next inspection. The recommended time is the number of flight hours required for the theoretical crack to grow to half its critical length assuming 100 percent humidity conditions. Figures 9a and 9b are printouts from the computer tape. The crack length, adjusted for environmental conditions, is 0.00870 inches compared to the 0.00950-inch growth predicted by the C-5A crack monitoring program(5).

5.2 General Corrosion

In checking for general corrosion the assumption was made that, at corrosion prone areas on the aircraft, the protective coatings have been mechanically abraded or worn away and some metal is exposed. The trial run was made for 2024-T3 clad aluminum. Figures 10a and 10b show the depth of corrosion which would occur in the relatively mild environments of Dobbins and Edwards Air Force Bases. The corrosion at the end of 1-year would be 0.12 mils which is in line with test data for clad aluminum alloys in moderate environments.

5.3 Coating Degradation

The coating degradation module gives the time required for the standard Air Force coating system, composed of the MIL-P-23377 epoxy polyamide primer and MIL-C-83286 polyurethane top coat, to begin to crack around fasteners and be eroded on engine cowlings and leading edges of wings. In a moderately severe environment, initial breakdown of the coating system occurs after 24 months. The computer program adjusts the coating degradation rate for severity of environment and gives a continuous readout of the time until the next recommended Intensive Paint Renewal. This consists of a thorough cleaning and touchup of all degraded areas. The recommended time for complete repainting is every fourth paint renewal interval. The predicted coating life computer printout for C-5A aircraft 668304, for its first 61 missions, is reproduced in Figure 11.

```
ANALYSIS AREA 5250551
7175-T73 ALUMINUM
INITIAL CRACK LENGTH = 0.005000 INCHES

          DURATION                               *    90% HUMIDITY    *
MISSION  GROUND  FLIGHT          BASE            *  FATIGUE   CRACK   *   STRESS   ADJUSTED
                                                 *  GROWTH    LENGTH  *   GROWTH   FATIGUE    CRACK
                                                                                   GROWTH     LENGTH
-----------------------------------------------------------------------------------------------------
   1       0.0    1.9     DOBBINS AFB            *  0.00005  0.00505  *  0.00000  0.00005  0.00505
   2      97.8    1.2     DOBBINS AFB            *  0.00005  0.00510  *  0.00000  0.00005  0.00510
   2       0.2    0.3     DOBBINS AFB            *  0.00005  0.00515  *  0.00000  0.00005  0.00515
   2       0.2    0.2     DOBBINS AFB            *  0.00005  0.00520  *  0.00000  0.00005  0.00520
   3     298.6    0.8     DOBBINS AFB            *  0.00005  0.00525  *  0.00000  0.00005  0.00525
   4       5.6    0.6     DOBBINS AFB            *  0.00005  0.00530  *  0.00000  0.00005  0.00530
   5    1322.9    2.5     DOBBINS AFB            *  0.00005  0.00535  *  0.00000  0.00005  0.00535
   5       0.4    0.7     DOBBINS AFB            *  0.00005  0.00540  *  0.00000  0.00005  0.00540
   6     150.7    3.5     DOBBINS AFB            *  0.00005  0.00545  *  0.00000  0.00005  0.00545
   6       0.3    0.7     DOBBINS AFB            *  0.00005  0.00550  *  0.00000  0.00005  0.00550
   7     240.3    1.7     DOBBINS AFB            *  0.00005  0.00555  *  0.00000  0.00005  0.00555
   7       0.2    1.5     DOBBINS AFB            *  0.00005  0.00560  *  0.00000  0.00005  0.00560
   7       0.2    0.2     DOBBINS AFB            *  0.00005  0.00565  *  0.00000  0.00005  0.00565
   8     224.1    1.9     DOBBINS AFB            *  0.00005  0.00570  *  0.00000  0.00005  0.00570
   9      48.7    5.5     DOBBINS AFB            *  0.00005  0.00575  *  0.00000  0.00005  0.00575
  10     128.1    1.5     DOBBINS AFB            *  0.00005  0.00580  *  0.00000  0.00005  0.00580
  10       0.3    3.9     DOBBINS AFB            *  0.00005  0.00585  *  0.00000  0.00005  0.00585
  11      27.9    0.2     DOBBINS AFB            *  0.00005  0.00590  *  0.00000  0.00005  0.00590
  12       4.4    0.6     DOBBINS AFB            *  0.00005  0.00595  *  0.00000  0.00005  0.00595
  13     456.9    2.8     DOBBINS AFB            *  0.00005  0.00600  *  0.00000  0.00005  0.00600
  14      27.3    2.9     DOBBINS AFB            *  0.00005  0.00605  *  0.00000  0.00005  0.00605
  15      52.0    0.3     DOBBINS AFB            *  0.00005  0.00610  *  0.00000  0.00005  0.00610
  16      52.3    7.8     DOBBINS AFB            *  0.00005  0.00615  *  0.00000  0.00005  0.00615
  17     120.8    0.4     DOBBINS AFB            *  0.00005  0.00620  *  0.00000  0.00005  0.00620
  18     149.8    0.9     DOBBINS AFB            *  0.00005  0.00625  *  0.00000  0.00005  0.00625
  19     125.4    3.4     DOBBINS AFB            *  0.00005  0.00630  *  0.00000  0.00005  0.00630
  19       0.4    0.6     DOBBINS AFB            *  0.00005  0.00635  *  0.00000  0.00005  0.00635
  20      28.3    1.4     DOBBINS AFB            *  0.00005  0.00640  *  0.00000  0.00005  0.00640
  20       0.2    5.3     DOBBINS AFB            *  0.00005  0.00645  *  0.00000  0.00005  0.00645
  21    2089.2    1.8     DOBBINS AFB            *  0.00005  0.00650  *  0.00000  0.00005  0.00650
  22     149.6    5.6     DOBBINS AFB            *  0.00005  0.00655  *  0.00000  0.00005  0.00655
  22       0.2    0.4     DOBBINS AFB            *  0.00005  0.00660  *  0.00000  0.00005  0.00660
  23      73.2    1.6     DOBBINS AFB            *  0.00005  0.00665  *  0.00000  0.00005  0.00665
  24      54.9    4.3     DOBBINS AFB            *  0.00005  0.00670  *  0.00000  0.00005  0.00670
  25      32.8    8.0     EDWARDS AFB            *  0.00005  0.00675  *  0.00000  0.00003  0.00673
  26      56.2    3.9     EDWARDS AFB            *  0.00005  0.00680  *  0.00000  0.00003  0.00677
  27      50.0    0.5     DOBBINS AFB            *  0.00005  0.00685  *  0.00000  0.00005  0.00682
  27       0.3    0.8     DOBBINS AFB            *  0.00005  0.00690  *  0.00000  0.00005  0.00687
  28       1.9    4.2     DOBBINS AFB            *  0.00005  0.00695  *  0.00000  0.00005  0.00692
  29     153.7    4.2     EDWARDS AFB            *  0.00005  0.00700  *  0.00000  0.00003  0.00695
  30      27.9    6.2     EDWARDS AFB            *  0.00005  0.00705  *  0.00000  0.00003  0.00699
  31      49.7    6.3     EDWARDS AFB            *  0.00005  0.00710  *  0.00000  0.00003  0.00702
  32      82.3    8.1     EDWARDS AFB            *  0.00005  0.00715  *  0.00000  0.00003  0.00706
  33     144.3    1.6     EDWARDS AFB            *  0.00005  0.00720  *  0.00000  0.00003  0.00709
  34      62.2    5.0     EDWARDS AFB            *  0.00005  0.00725  *  0.00000  0.00003  0.00713
  35      56.7    8.1     EDWARDS AFB            *  0.00005  0.00730  *  0.00000  0.00003  0.00716
  36     267.3    2.9     EDWARDS AFB            *  0.00005  0.00735  *  0.00000  0.00003  0.00720
  37      59.8    6.2     EDWARDS AFB            *  0.00005  0.00740  *  0.00000  0.00003  0.00723
  38      56.2    4.7     EDWARDS AFB            *  0.00005  0.00745  *  0.00000  0.00003  0.00727
  39       3.4    3.7     EDWARDS AFB            *  0.00005  0.00750  *  0.00000  0.00003  0.00730
  40      32.3    1.1     EDWARDS AFB            *  0.00005  0.00755  *  0.00000  0.00003  0.00734
```

Figure 9a. Crack Growth Computer Printout

```
41    25.6   3.9   EDWARDS AFB       *  0.00005  0.00760  *  0.00000  0.00003  0.00737
41     0.1   5.6   EDWARDS AFB       *  0.00005  0.00765  *  0.00000  0.00003  0.00741
42   136.4   4.7   EDWARDS AFB       *  0.00005  0.00770  *  0.00000  0.00003  0.00744
42     0.5   3.6   EDWARDS AFB       *  0.00005  0.00775  *  0.00000  0.00003  0.00748
43    24.5   1.1   EDWARDS AFB       *  0.00005  0.00780  *  0.00000  0.00003  0.00751
44   264.7   4.5   EDWARDS AFB       *  0.00005  0.00785  *  0.00000  0.00003  0.00755
45    57.6   3.2   EDWARDS AFB       *  0.00005  0.00790  *  0.00000  0.00003  0.00758
45     0.3   3.5   EDWARDS AFB       *  0.00005  0.00795  *  0.00000  0.00003  0.00762
46    54.7   0.1   EDWARDS AFB       *  0.00005  0.00800  *  0.00000  0.00003  0.00765
46     0.2   0.1   EDWARDS AFB       *  0.00005  0.00805  *  0.00000  0.00003  0.00769
46     0.2   0.2   EDWARDS AFB       *  0.00005  0.00810  *  0.00000  0.00003  0.00772
46     0.4   0.2   EDWARDS AFB       *  0.00005  0.00815  *  0.00000  0.00003  0.00776
46     0.3   0.2   EDWARDS AFB       *  0.00005  0.00820  *  0.00000  0.00003  0.00779
47    96.5   0.3   EDWARDS AFB       *  0.00005  0.00825  *  0.00000  0.00003  0.00783
47     0.3   0.3   EDWARDS AFB       *  0.00005  0.00830  *  0.00000  0.00003  0.00786
47     0.4   0.8   EDWARDS AFB       *  0.00005  0.00835  *  0.00000  0.00003  0.00790
47     0.3   0.4   EDWARDS AFB       *  0.00005  0.00840  *  0.00000  0.00003  0.00793
47     0.2   0.6   EDWARDS AFB       *  0.00005  0.00845  *  0.00000  0.00003  0.00797
47     0.5   1.4   EDWARDS AFB       *  0.00005  0.00850  *  0.00000  0.00003  0.00800
47     0.2   0.2   EDWARDS AFB       *  0.00005  0.00855  *  0.00000  0.00003  0.00804
47     0.1   0.3   EDWARDS AFB       *  0.00005  0.00860  *  0.00000  0.00003  0.00807
48    61.1   3.6   EDWARDS AFB       *  0.00005  0.00865  *  0.00000  0.00003  0.00811
48     2.2   0.6   EDWARDS AFB       *  0.00005  0.00870  *  0.00000  0.00003  0.00814
49   337.4   2.2   EDWARDS AFB       *  0.00005  0.00875  *  0.00000  0.00003  0.00818
50     0.6   4.1   EDWARDS AFB       *  0.00005  0.00880  *  0.00000  0.00003  0.00821
51    32.6   3.5   EDWARDS AFB       *  0.00005  0.00885  *  0.00000  0.00003  0.00825
52    32.4   3.8   EDWARDS AFB       *  0.00005  0.00890  *  0.00000  0.00003  0.00828
53    25.7   4.1   EDWARDS AFB       *  0.00005  0.00895  *  0.00000  0.00003  0.00832
54   122.9   2.8   EDWARDS AFB       *  0.00005  0.00900  *  0.00000  0.00003  0.00835
55    97.7   0.2   EDWARDS AFB       *  0.00005  0.00905  *  0.00000  0.00003  0.00839
55     0.3   0.1   EDWARDS AFB       *  0.00005  0.00910  *  0.00000  0.00003  0.00842
55     0.6   0.2   EDWARDS AFB       *  0.00005  0.00915  *  0.00000  0.00003  0.00846
56     6.2   2.2   EDWARDS AFB       *  0.00005  0.00920  *  0.00000  0.00003  0.00849
57    26.5   0.2   EDWARDS AFB       *  0.00005  0.00925  *  0.00000  0.00003  0.00853
57     0.2   0.3   EDWARDS AFB       *  0.00005  0.00930  *  0.00000  0.00003  0.00856
58     0.5   1.0   EDWARDS AFB       *  0.00005  0.00935  *  0.00000  0.00003  0.00860
58   145.0   3.4   EDWARDS AFB       *  0.00005  0.00940  *  0.00000  0.00003  0.00863
60    32.5   4.4   EDWARDS AFB       *  0.00005  0.00945  *  0.00000  0.00003  0.00867
61   360.9   5.8   EDWARDS AFB       *  0.00005  0.00950  *  0.00000  0.00003  0.00870

FINAL CRACK LENGTH = 0.008705 INCHES
RECOMMENDED TIME TO NEXT INSPECTION =   5546.1 FLIGHT HOURS
```

Figure 9b. Crack Growth Computer Printout.

```
C-5A AIRCRAFT NUMBER 668304 PREDICTED GENERAL CORROSION

   INITIAL CORROSION DEPTH =  0.000 MILS IN 2024-T3 CLAD ALUMINUM

                                   ACTUAL TIME
MISSION     AIRCRAFT STATION       ON STATION
                                    (MONTHS)        PREDICTED CORROSION DEPTH
                                                             (MILS)
    1        DOBBINS AFB              0.00                   0.000
    2        DOBBINS AFB              0.14                   0.001
    2        DOBBINS AFB              0.00                   0.001
    2        DOBBINS AFB              0.00                   0.001
    3        DOBBINS AFB              0.41                   0.003
    4        DOBBINS AFB              0.01                   0.003
    5        DOBBINS AFB              1.82                   0.029
    5        DOBBINS AFB              0.00                   0.029
    6        DOBBINS AFB              0.21                   0.030
    6        DOBBINS AFB              0.00                   0.030
    7        DOBBINS AFB              0.33                   0.032
    7        DOBBINS AFB              0.00                   0.032
    7        DOBBINS AFB              0.00                   0.032
    8        DOBBINS AFB              0.31                   0.034
    9        DOBBINS AFB              0.07                   0.034
   10        DOBBINS AFB              0.18                   0.035
   10        DOBBINS AFB              0.01                   0.035
   11        DOBBINS AFB              0.04                   0.035
   12        DOBBINS AFB              0.01                   0.035
   13        DOBBINS AFB              0.63                   0.040
   14        DOBBINS AFB              0.04                   0.040
   15        DOBBINS AFB              0.07                   0.041
   16        DOBBINS AFB              0.08                   0.041
   17        DOBBINS AFB              0.17                   0.042
   18        DOBBINS AFB              0.21                   0.043
   19        DOBBINS AFB              0.18                   0.043
   19        DOBBINS AFB              0.00                   0.043
   20        DOBBINS AFB              0.04                   0.044
   20        DOBBINS AFB              0.01                   0.044
   21        DOBBINS AFB              2.86                   0.095
   22        DOBBINS AFB              0.21                   0.096
   22        DOBBINS AFB              0.00                   0.096
   23        DOBBINS AFB              0.10                   0.096
   24        DOBBINS AFB              0.08                   0.096
   25        EDWARDS AFB              0.06                   0.097
   26        EDWARDS AFB              0.08                   0.097
   27        DOBBINS AFB              0.07                   0.097
   27        DOBBINS AFB              0.00                   0.097
   28        DOBBINS AFB              0.01                   0.097
   29        EDWARDS AFB              0.22                   0.098
   30        EDWARDS AFB              0.05                   0.098
   31        EDWARDS AFB              0.08                   0.098
   32        EDWARDS AFB              0.12                   0.099
   33        EDWARDS AFB              0.20                   0.100
   34        EDWARDS AFB              0.12                   0.100
   35        EDWARDS AFB              0.09                   0.100
   36        EDWARDS AFB              0.37                   0.103
   37        EDWARDS AFB              0.09                   0.103
   38        EDWARDS AFB              0.08                   0.103
   39        EDWARDS AFB              0.01                   0.103
   40        EDWARDS AFB              0.05                   0.104
   41        EDWARDS AFB              0.04                   0.104
```

Figure 10a. Predicted General Corrosion Computer Printout

```
41        EDWARDS AFB             0.01                         0.104
42        EDWARDS AFB             0.19                         0.105
42        EDWARDS AFB             0.01                         0.105
43        EDWARDS AFB             0.04                         0.105
44        EDWARDS AFB             0.37                         0.107
45        EDWARDS AFB             0.08                         0.107
45        EDWARDS AFB             0.01                         0.107
46        EDWARDS AFB             0.08                         0.107
46        EDWARDS AFB             0.00                         0.107
46        EDWARDS AFB             0.00                         0.107
46        EDWARDS AFB             0.00                         0.107
46        EDWARDS AFB             0.00                         0.107
47        EDWARDS AFB             0.13                         0.108
47        EDWARDS AFB             0.00                         0.108
47        EDWARDS AFB             0.00                         0.108
47        EDWARDS AFB             0.00                         0.108
47        EDWARDS AFB             0.00                         0.108
47        EDWARDS AFB             0.00                         0.108
47        EDWARDS AFB             0.00                         0.108
47        EDWARDS AFB             0.00                         0.108
48        EDWARDS AFB             0.09                         0.108
48        EDWARDS AFB             0.00                         0.108
49        EDWARDS AFB             0.47                         0.112
50        EDWARDS AFB             0.01                         0.112
51        EDWARDS AFB             0.05                         0.112
52        EDWARDS AFB             0.05                         0.112
53        EDWARDS AFB             0.04                         0.112
54        EDWARDS AFB             0.17                         0.113
55        EDWARDS AFB             0.13                         0.113
55        EDWARDS AFB             0.00                         0.113
55        EDWARDS AFB             0.00                         0.113
56        EDWARDS AFB             0.01                         0.113
57        EDWARDS AFB             0.04                         0.113
57        EDWARDS AFB             0.00                         0.113
58        EDWARDS AFB             0.00                         0.113
58        EDWARDS AFB             0.20                         0.114
60        EDWARDS AFB             0.05                         0.114
61        EDWARDS AFB             0.50                         0.118

       ESTIMATED FINAL CORROSION DEPTH =  0.118 MILS
```

Figure 10b. Predicted General Corrosion Computer Printout.

```
C-5A AIRCRAFT NUMBER 668304 PREDICTED COATING LIFE

    INITIAL TIME TO NEXT INTENSIVE PAINT RENEWAL = 24.0 MONTHS
    (BASED ON TIME IN MODERATELY SEVERE ENVIRONMENT)

                                       ACTUAL TIME     APPROXIMATE COATING LIFE IN
MISSION      AIRCRAFT STATION          ON STATION     MODERATELY SEVERE ENVIRONMENT
                                        (MONTHS)                 (MONTHS)
                                                           USED         REMAINING
    1          DOBBINS  AFB               0.00             0.00           24.00
    2          DOBBINS  AFB               0.14             0.09           23.91
    2          DOBBINS  AFB               0.00             0.00           23.91
    2          DOBBINS  AFB               0.00             0.00           23.91
    3          DOBBINS  AFB               0.41             0.27           23.63
    4          DOBBINS  AFB               0.01             0.01           23.63
    5          DOBBINS  AFB               1.82             1.21           22.42
    5          DOBBINS  AFB               0.00             0.00           22.42
    6          DOBBINS  AFB               0.21             0.14           22.28
    6          DOBBINS  AFB               0.00             0.00           22.27
    7          DOBBINS  AFB               0.33             0.22           22.05
    7          DOBBINS  AFB               0.00             0.00           22.05
    7          DOBBINS  AFB               0.00             0.00           22.05
    8          DOBBINS  AFB               0.31             0.21           21.85
    9          DOBBINS  AFB               0.07             0.05           21.80
   10          DOBBINS  AFB               0.18             0.12           21.68
   10          DOBBINS  AFB               0.01             0.00           21.67
   11          DOBBINS  AFB               0.04             0.03           21.65
   12          DOBBINS  AFB               0.01             0.00           21.64
   13          DOBBINS  AFB               0.63             0.42           21.22
   14          DOBBINS  AFB               0.04             0.03           21.20
   15          DOBBINS  AFB               0.07             0.05           21.15
   16          DOBBINS  AFB               0.08             0.05           21.09
   17          DOBBINS  AFB               0.17             0.11           20.98
   18          DOBBINS  AFB               0.21             0.14           20.85
   19          DOBBINS  AFB               0.18             0.12           20.73
   19          DOBBINS  AFB               0.00             0.00           20.73
   20          DOBBINS  AFB               0.04             0.03           20.70
   20          DOBBINS  AFB               0.01             0.01           20.69
   21          DOBBINS  AFB               2.86             1.91           18.79
   22          DOBBINS  AFB               0.21             0.14           18.64
   22          DOBBINS  AFB               0.00             0.00           18.64
   23          DOBBINS  AFB               0.10             0.07           18.57
   24          DOBBINS  AFB               0.08             0.05           18.52
   25          EDWARDS  AFB               0.06             0.06           18.46
   26          EDWARDS  AFB               0.08             0.08           18.38
   27          DOBBINS  AFB               0.07             0.05           18.34
   27          DOBBINS  AFB               0.00             0.00           18.34
   28          DOBBINS  AFB               0.01             0.01           18.33
   29          EDWARDS  AFB               0.22             0.22           18.11
   30          EDWARDS  AFB               0.05             0.05           18.07
   31          EDWARDS  AFB               0.08             0.08           17.99
   32          EDWARDS  AFB               0.12             0.12           17.87
   33          EDWARDS  AFB               0.20             0.20           17.67
   34          EDWARDS  AFB               0.12             0.12           17.55
   35          EDWARDS  AFB               0.09             0.09           17.46
   36          EDWARDS  AFB               0.37             0.37           17.09
   37          EDWARDS  AFB               0.09             0.09           16.99
   38          EDWARDS  AFB               0.08             0.08           16.91
   39          EDWARDS  AFB               0.01             0.01           16.90
```

Figure 11a. Predicted Coating Life Computer Printout

```
40        EDWARDS AFB           0.05          0.05          16.86
41        EDWARDS AFB           0.04          0.04          16.82
41        EDWARDS AFB           0.01          0.01          16.81
42        EDWARDS AFB           0.19          0.19          16.61
42        EDWARDS AFB           0.01          0.01          16.61
43        EDWARDS AFB           0.04          0.04          16.57
44        EDWARDS AFB           0.37          0.37          16.21
45        EDWARDS AFB           0.08          0.08          16.12
45        EDWARDS AFB           0.01          0.01          16.12
46        EDWARDS AFB           0.08          0.08          16.04
46        EDWARDS AFB           0.00          0.00          16.04
46        EDWARDS AFB           0.00          0.00          16.04
46        EDWARDS AFB           0.00          0.00          16.04
46        EDWARDS AFB           0.00          0.00          16.04
47        EDWARDS AFB           0.13          0.13          15.91
47        EDWARDS AFB           0.00          0.00          15.91
47        EDWARDS AFB           0.00          0.00          15.90
47        EDWARDS AFB           0.00          0.00          15.90
47        EDWARDS AFB           0.00          0.00          15.90
47        EDWARDS AFB           0.00          0.00          15.90
47        EDWARDS AFB           0.00          0.00          15.90
47        EDWARDS AFB           0.00          0.00          15.90
48        EDWARDS AFB           0.09          0.09          15.81
48        EDWARDS AFB           0.00          0.00          15.81
49        EDWARDS AFB           0.47          0.47          15.34
50        EDWARDS AFB           0.01          0.01          15.34
51        EDWARDS AFB           0.05          0.05          15.29
52        EDWARDS AFB           0.05          0.05          15.24
53        EDWARDS AFB           0.04          0.04          15.20
54        EDWARDS AFB           0.17          0.17          15.02
55        EDWARDS AFB           0.13          0.13          14.89
55        EDWARDS AFB           0.00          0.00          14.89
55        EDWARDS AFB           0.00          0.00          14.89
56        EDWARDS AFB           0.01          0.01          14.88
57        EDWARDS AFB           0.04          0.04          14.84
57        EDWARDS AFB           0.00          0.00          14.84
58        EDWARDS AFB           0.00          0.00          14.84
58        EDWARDS AFB           0.20          0.20          14.63
60        EDWARDS AFB           0.05          0.05          14.58
61        EDWARDS AFB           0.50          0.50          14.08

   APPROXIMATE TIME UNTIL NEXT INTENSIVE PAINT RENEWAL = 14.08 MONTHS
   APPROXIMATE TIME UNTIL NEXT COMPLETE REPAINT = 86.08 MONTHS
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Figure 11b. Predicted Coating Life Computer Printout.

6.0 DISCUSSION

The Predictive Corrosion Modeling Program is designed to give optimum inspection and maintenance scheduling for the major types of crack growth, corrosion damage, and coating degradation problems which may occur on C-5 aircraft. Specific aircraft can be quickly checked for potential crack growth in critical areas, for probable corrosion damage to exposed structural alloys, or for the condition of the aircraft coating system.

Even new aircraft will have areas where the protective system has been mechanically abraded and bare metal is exposed. It is, therefore, necessary to assume the existence of some bare metal and to examine the corrosion prone areas at each recommended inspection interval.

6.1 Corrosion Prone Areas

Following is a summary of the C-5A corrosion prone areas described in T.O. 1C-5A-23 (4):

1. Wing - Trailing edges of control surfaces and attachment areas for the actuating mechanisms of these control surfaces most likely will corrode. Honeycomb sandwich components which are used widely throughout the wing, should be checked for damage which could cause corrosion. Engine exhaust contains fuel residue which may collect as soot and hard carbon on surfaces in exhaust paths and when moisture is added staining and pitting may be found on unprotected surfaces. These exhaust exposure areas require frequent cleaning and close watching for corrosion.

2. Fuselage - The types of corrosion which occur in the fuselage varies according to the area involved. Problems such as water accumulation, condensation, leaking latrine fluids, collection of dirt, chemical attack, damaged finishes, dissimilar metals and exposure all contribute to corrosion problems associated with the fuselage.

3. Empennage - The areas most prone to corrosion are generally the attachment areas for the actuating mechanism of the control surfaces. Other corrosion prone areas include the rudder hinge support fittings, all of the fittings in the horizontal stabilizer system and rudder and elevator wells.

4. Pylons and Nacelles - Corrosion in the pylon/nacelle area is largely due to the fact that there are many areas in which soil can accumulate. Attach fittings for pylon-to-wing and engine-to-pylon are subject to this soil and moisture and are therefore susceptible to corrosion. Many areas such as hinge points, latch points, actuators, and cowl doors are made of corrosion prone materials.

5. Landing Gear - when surface finishes on main and nose landing gear are not properly maintained corrosion may occur due to environmental exposure and dissimilar metals. The main landing gear components subject to corrosion include shock struts and bogie beams, drag brace, retract arm, yoke, axles and many others. The nose landing gear axles, wheels, actuator assembly, and axle bearing lands are all prone to corrosion.

6. Internal Areas - In its present form, the program will not predict corrosion damage in latrine or galley areas, or which may be caused by spilled fluids in the battery storage areas. These are "hot spots" which should be inspected at each home station inspection. If battery fluid comes into contact with bare aluminum, extensive corrosion damage can occur in just a few hours. In such critical areas it is essential that the protective coating systems be inspected at frequent intervals and that the necessary repair and maintenance be accomplished without delay.

6.2 Future Work

Task IV, the next task in completing the project is to validate the computer model by comparing the predictions with actual corrosion histories of C-5A aircraft. The general corrosion and coating degradation predictions will be checked by selecting specific aircraft and determining the environmental conditions in which they operated during the first few years of service. With this information as input, the predictive corrosion computer program will disclose the times at which significant amounts of corrosion damage and coating degradation should have occurred. These predictions will then be compared with a plot of corrosion control manhours for the corrosion prone areas of the aircraft.

The validation of the crack growth module of the computer program will be accomplished by comparing analytical crack growth lengths, which have been adjusted for environmental conditions during the test period, with actual cracks in the test article used in the C-5A Modified Wing Structural Test Evaluation(6). During the C-5A Modified wing test approximately 100 cracks initiated from intentional sawcuts made in the wing. A comparison of actual and predicted crack growth was performed for 19 of these cracks representing various configurations and spanwise locations.

The final task, Task V, will be to evaluate the efficiency of a new maintenance scheduling decision logic which integrates the predictive corrosion model with the Air Force Reliability Centered Maintenance (RCM) programs. RCM currently determines inspection intervals and scheduled maintenance intervals based upon the probability of an item failing within that interval, and upon the criticality of that failure. Corrosion is a "malfunction" or "failure mode" which is experienced constantly, and a tool which can accurately predict the frequency and effect of corrosion occurrence will make an important contribution toward the objectives of Reliability Centered Maintenance programs.

As a part of the final task, the feasibility of modifying the current maintenance activity control systems to include the results of the predictive corrosion model will be investigated. If feasible, the necessary changes to the current system will be identified. The impact of making these changes will be estimated from the standpoint of cost of incorporation and cost increases/decreases of maintenance activity, as well as improvement in operational readiness of the aircraft. The operational readiness improvement aspect would come from being able to better predict corrosion problems so that preventive measures could be taken in advance or, at least, the logistical support needed (maintenance personnel, equipment, spares, etc.) would be ready and available when needed.

6.3 VAX-11 Computer Tape

The VAX-11 computer program tape is complete except for the module which will match the recommended inspection times with the scheduled maintenance operations for specific C-5 aircraft and will select the closest scheduled time for performing a corrosion-related work task. For the time being this matching operation will be performed manually.

A complete reproduction of the VAX-11 computer program in included in Volume II Appendix A. This Volume II is available only from AFWAL/MLSA, WPAFB OH, 45433-6533 to requesters with valid need to know requirements. Copies of the VAX-11 computer tape or copies of the program are available only from AFWAL/MLSA, WPAFB OH, 45433-6533.

7.0 CONCLUSIONS

1. A VAX-11 computer program which will predict the degree of corrosion sustained by aircraft alloys, the degradation of aircraft coating systems, and the fatigue cracking of aircraft alloys in a variety of environments has been developed.

2. The predictive corrosion modeling program will enable optimum inspection and maintenance scheduling for the major types of crack growth, corrosion damage, and coating degradation problems which may occur on C-5A aircraft.

3. The predictive corrosion modeling program can be readily modified for use on the C-141, C-130, and B-52 and other aircraft fleets which have crack monitoring programs.

4. The implementation and use of the predictive corrosion modeling program will minimize unnecessary inspections and will enable corrosion damage to be prevented or repaired at minimum cost.

8.0 RECOMMENDATIONS

The completion of this program and its use to schedule inspection and maintenance operations for the C-5 and other aircraft fleets should save the Air Force millions of dollars annually by enabling emphasis on corrosion prevention instead of repair and replacement of corroded parts. It is recommended that Task IV, the validation of the program, and Task V, the study on the best way of integrating it with current Air Force structural integrity programs, be initiated as soon as possible.

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