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DIRECTORATE OF MATERIALS R & D (AVIATION)

THE CORROSION PROPERTIES OF AIRFRAME CONTAMINANTS

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R Kohler and J Scott

BRITISH AIRCRAFT CORPORATION LIMITED

COMMERCIAL AIRCRAFT DIVISION

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FOREWORD

This report describes work carried out by British Aircraft Corporation, Commercial Aircraft Division, Weybridge, under Ministry of Defence (PE) Contract KS/1/0692/CB43A2.

The work was supervised by MAT.F2 under the direction of AD MAT.FI.

SUMMARY

The investigation was concerned with the analysis and corrosion testing of a series of fluids collected from the bilge areas of aircraft of the Royal Air Force, Air Support Command. Assessments were also made of the influence of stress, reduced oxygen levels, microbiological action and general environment when relating the corrosion behaviour.

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TABLES

FIGURES

1. INTRODUCTION

1.1. A great deal of research has been conducted on aircraft alloys in assessing their characteristics towards various types of corrosion; notably pitting, intergranular (exfoliation), microbiological and stress corrosion. This work has usually involved the use of synthetic corrodents formulated in the laboratory, but little work appears to have been performed upon corrosive fluids actually existing in or on the aircraft structure.

1.2. The purpose of this programme was to investigate both chemically and microbiologically the nature and composition of airframe fluids sampled from aircraft of the Royal Air Force Air Support Command. These fluids would then be used for a series of corrosion tests using the appropriate aircraft alloys.

1.3. The programme was designed in an attempt to relate the recorded history of airframe corrosion with the behaviour of the fluids, collected from the aircraft, under laboratory corrosion tests. Fluids which exhibited anomalous behaviour in the corrosion tests, being either more or less corrosive than would be expected from analyses for known corrodents (e.g. chloride), were to be further investigated both chemically and microbiologically. All test work was to be related to similar tests conducted on a series of synthetic corrodents.

1.4. Collection of samples was spread over a period of two years and was scheduled to take place during the Base II and Base III servicing periods. Sampling was to be performed by both R.A.F. and B.A.C. personnel, and was to be accompanied by as full an inspection of the airframe as was possible. This was limited to the structure available for examination as detailed by the appropriate service schedule.

2. TEST PROGRAMME

2.1. Collection of Bilge Fluid Samples

Sampling was carried out in conjunction with personnel of the Royal Air Force, Air Support Command, whose assistance is gratefully acknowledged. After preliminary meetings between A.S.C., Ministry of Aviation Supply and B.A.C., two aircraft were chosen as being the most likely to produce representative bilge fluid samples. These were the Britannia and Comet. V.C.10 aircraft were omitted from routine sampling procedures because automatic draining resulted in little bilge fluid collecting. Isolated samples were taken from this aircraft on a non-routine basis, and also from Hercules aircraft.

2.1.1. Sample Areas

Comet Aircraft

1. The forward freight bay.
2. The hydraulic bay.
3. The rear freight bay.
4. Servodyne bays.

Britannia Aircraft

1. Wing box
2. Front of rear freight bay.
3. Rear freight bay.

Isolated samples were also taken from other areas.

2.2. Examination of Aircraft

Sample collection was normally at the Base II and Base III servicing of the aircraft. Wherever possible, an examination was made of the structure available for inspection in order to assess the corrosion behaviour of the aircraft. Efforts were made to assess, from the information available, the service history regarding corrosion of the aircraft under examination. In this respect, discussions with personnel at the Central Servicing Development Establishment, Royal Air Force, Swanton Morley were particularly valuable.

2.3. Corrosion Testing

2.3.1. Standard Laboratory Corrosion Test

Much of the early work in the programme was towards the development of a laboratory corrosion test that was both rapid and reproducible, was applicable with a small quantity of fluid, and gave a reasonable sorting of the fluids under test. The vibrating test described in para. 3.1. was shown to be a more rapid method than the normally accepted immersion tests. This method was used as the standard corrosion test for all samples examined.

2.3.2. Limited Oxygen Supply Tests

Crevice corrosion of aluminium alloys is known to occur in environments where there is insufficient oxygen available to maintain the natural protective oxide film. Some work was undertaken to investigate corrosion testing under these conditions. Details are given in para. 3.3.

2.3.3. Special Corrosion Tests

Corrosion tests were developed during the programme, designed to simulate specific examples of corrosion found during aircraft examinations, viz :-

1. Investigation of corrosion of carpeted DTD.5020 machined floor panels. Test work as detailed in para. 3.2.1.

2. Investigation into the corrosion of a floor area adjacent to a galley. Test work as detailed in para. 3.2.2.

2.4. Stress Corrosion Tests.

Stress corrosion tests were performed upon a number of fluids chosen because of their behaviour under the standard laboratory corrosion test. These were conducted on DTD.5050 alloy and 2024 T.351 alloy at the 60% and 90% proof levels. Details are given in para. 3.4. and results in Table 4.

2.5. Chemical Examination of Fluids.

Chemical analyses were performed on all bilge fluid samples. Generally analysis was limited to three types of ion. Namely :-

(1) Those reported to act as corrodents in aluminium alloy systems.

(2) Those reported to act as inhibitors in aluminium alloy systems.

(3) Those indicating that corrosion might already have occurred.[1]

Specific bilge fluids which exhibited anomalous behaviour in the corrosion tests were further examined chemically. A series of typical aircraft fluids including toilet fluids and some beverages were also examined. All results are given in Tables 1 and 7.

2.6. Microbiological Work.

Microbiological work was in conjunction with the Commonwealth Mycological Institute, Kew, whose assistance is gratefully acknowledged. The test programme was broadly defined in two areas :-

(1) Identification of the microbiological species existing in the various aircraft environments together with counts of the total number of cells per millilitre present in the "as received" sample. Results are given in Table 2.

(2) Assessment of the role, as corrosive agents, of the microbiological species identified during the programme. This involved monitoring the changes in microbiological population during corrosion tests using the test method detailed in para. 3.5.2. This work was performed using both bilge fluid samples and synthetic samples inoculated with microbial species. Test results are detailed in Table 3.

In addition, work was carried out upon sections of the carpet recovered from the corroded DTD.5020 panels mentioned in para. 2.3.2. in order to assess the role, if any, of microbiological species in this corrosion. Details of this work are given in para. 3.2.1.3.

3. EXPERIMENTAL PROCEDURES

3.1. Laboratory Corrosion Test

Initially, samples 1 to 23 in Table 1 were tested using a static partial immersion test. 2" x ½" x 18 s.w.g. B.S.L.71 specimens, radiused at one end, were pickled in chromic/sulphuric acid (method O Def. Stan. 03-2), rinsed in distilled water, air dried and weighed. The specimens were then partially immersed in 5 ml. of the test fluid contained in a 19 x 150 mm. test tube closed, but not sealed, with a polypropylene cap. After three weeks, the specimens were removed and the corrosion product dissolved in concentrated nitric acid. The specimens were then rinsed in distilled water, air dried and reweighed. Attack was found to be slight and confined to a narrow band around the liquid/air phase boundary.

Subsequently, repeat tests on these fluids and on all further fluids utilised a vibrating technique. This differed only in that the test tube system was subjected to 70 cps vertical oscillation, fed from a power oscillator at constant amplitude. This resulted in constant aeration of the sample and produced more rapid corrosion in a one week test period. This attack was relatively uniform and not confined solely to the interface. Where appropriate, pH values of the test solution were taken before and after test and also microbiological counts using the method detailed in para 3.5.2.

Control tests were carried out using distilled water and synthetic corrodents containing chloride and sulphate. Results are given in the following tables :-

Table 1 : Bilge Fluid Results.

Table 2 : Synthetic Solution and Blank Results.

Table 3 : Aircraft Contaminating Fluid Results.

3.2. Special Investigations

3.2.1. Investigation 1 : Severe Corrosion of Carpeted DTD.5020 Machined Floor Panels.

During the course of the programme, instances were reported of severe pitting corrosion of DTD.5020 machined floor panels on VC.10 aircraft No. XV107 in the vicinity of the rear galley. Complete penetration (0.1") of the fully protected and painted panels had occurred.

The corrosion product and aqueous extract from the carpet were both analysed and the aqueous extract used for corrosion and microbiological tests. In addition, a simulated aircraft environment test was performed comparing the aircraft carpet with a sample of new carpet.

3.2.1.1. Analysis of Corrosion Product

Samples of corrosion product varied in sodium chloride content from trace levels to fairly high concentrations of the order 0.1% w/w. pH value was approximately 9. No other factor was found to account for the severity of the corrosion.

3.2.1.2. Analysis of Aqueous Extracts from the Carpets

The test method used was that described in BS.3266:1960.

Carpet	From Aircraft XV 107		New Material	
Method of Extraction	Cold	Hot	Cold	Hot
pH	8.86	6.5	7.0	5.2
Chloride (As NaCl) gl^{-1}	0.45	3.9	0.24	1.5
Sulphate (As Na_2SO_4) gl^{-1}	0.32	5.9	0.21	2.1
Weight loss (Method para 3.1)	0.8 mg	-	0.8 mg	-

3.2.1.3. Microbiological Work - Carpet Samples Extraction Plate Count.

Small samples (2" x ¼") were cut from the carpet at positions both near to and remote from the galley door area. These were extracted in sterile bottles with 10 cc of 0.85% NaCl + 0.1% Nonidet P.40 (a non-ionic detergent) and shaken for 30 seconds on a mixer. The extract was plated out on both nutrient agar (N.A.) and malt extract agar (M.E.A.) and incubated at 30°C for 3 days. All samples developed microbiological growths, but none produced significantly high counts. All counts were in the region of 1×10^4.

3.2.1.4. Simulated Aircraft Environment Test.

Pieces of carpet of approximately 4" square were cut from the aircraft sample together with new carpet samples and placed in contact with 12 s.w.g. L71 aluminium alloy panels. The upper surface of the new carpet was microbiologically inoculated by placing in wet contact with the aircraft carpet. The specimens were maintained at 30°C and 100% R.H. for 63 days. Examinations by visual and radiographic methods were made at 7, 14, 29, 49 and 63 days. After 7 days, the uncovered areas of the panels were generally corroded whilst pitting corrosion was evident under both carpet samples. The pitting was slightly worse under the new carpet and the corrosion product was green. After 14 days, the corrosion under the sample of aircraft carpet was greater and became progressively worse throughout the test. After 63 days the corrosion was estimated to be 0.030" deep in places. Visible white fungal growth was present on the upper face of both carpets after 49 days. Control samples of L71 without carpet were generally corroded but essentially unpitted after 63 days.

3.2.2. Investigation 2 : Corrosion of a Floor Area Adjacent to a Galley.

Another example of corrosion of a floor area occurred during the programme which illustrated the effect of environment upon corrosion. This is shown in Fig.1 (plan view).

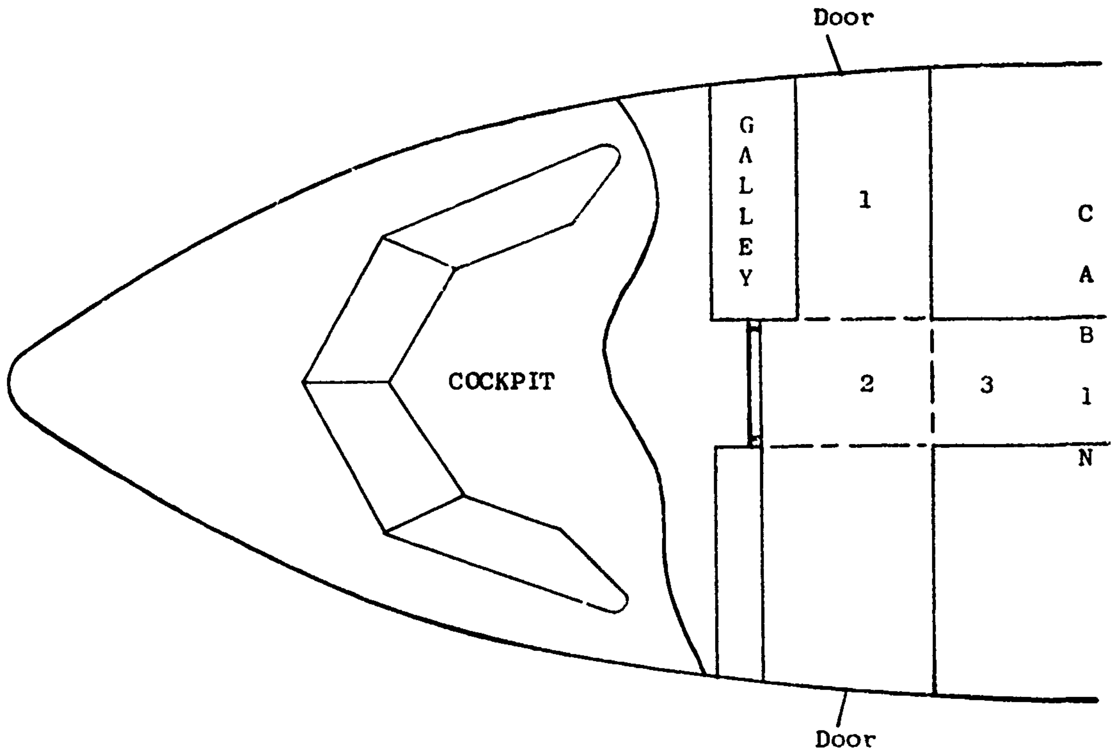

Fig.1 : FORWARD FUSELAGE AREA (SCHEMATIC)

Key: Area 1 Galley underfloor area: Fully painted open structure.

Area 2 PVC/Glasscloth sandwich construction placed on top of the fully painted floor.

Area 3 Fully painted area covered by a foam underlay and carpet.

Observed Effects

Area 1 No corrosion or deterioration of the paint scheme had occurred despite considerable contamination with galley spillage.

Area 2 No corrosion but the paint had been removed and a swirl pattern had appeared on the metal.

Area 3 The paint had blistered and fairly deep pitting corrosion of the metal floor had occurred.

A laboratory test was designed to simulate this condition. Two B.S.L72 sheets 3' x 2' were pretreated by the Alocrom 1200 process and painted with epoxy primer and finish to DTD.5567, as used on the aircraft. Half of the area of each sheet was covered; one with the sandwich construction, which is essentially non absorbent, and the other with foam underlay and carpet. Both constructions were placed in a gangway and wetted at intervals for three months. At the end of this period, neither of the two half areas of exposed paint showed serious signs of deterioration. Paint under the sandwich construction was observed to be blistered, but no corrosion had occurred. Paint under the carpet had discoloured but no blistering or corrosion had occurred.

3.3. Limited Oxygen Supply Tests

These tests were designed to investigate the effect of a reduced oxygen availability on the corrosion of aluminium alloys.

3.3.1. Thunberg Tube Test

2" x ½" x 18 s.w.g. B.S.L71 specimens radiused at one end were pickled in chromic/sulphuric acid (method O DEF STAN 03-2), rinsed in water, air dried and weighed. The specimens were then partially immersed in 5 ml. of fluid contained in a 19 x 150 mm. Thunberg tube (See Fig. II).

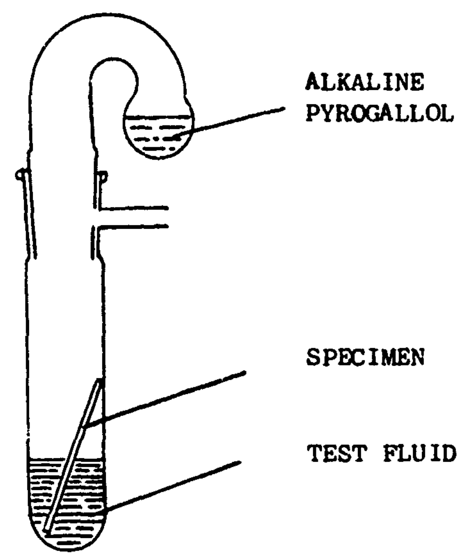

Fig.II : THUNBERG TUBE ASSEMBLY.

The tube was evacuated and the trap partly filled with pyrogallol to absorb oxygen. After one week the specimens were removed, the corrosion product cleaned off in a mixture of 2% chromic acid and 5% phosphoric acid at 80°C, rinsed in distilled water, air dried and reweighed. Test results are detailed in Table 6.

3.4. Stress Corrosion

3.4.1. Test Rig

The test rig used for stress corrosion tests was of the hydraulically operated constant load type. Each of the four channels was loaded by means of a hydraulic jack, the pressure on each being controlled by a dome regulator. Three specimens, as shown in Fig.III, were loaded in chain in each channel. Side plates enabled the load to be automatically re-applied to the chain when one of the specimens failed. The life of each specimen was timed by a digital electric time counter. The counter circuit was completed by wires attached to each end of the specimen. Failure of the specimen resulted in breakage of the wire and the circuit.

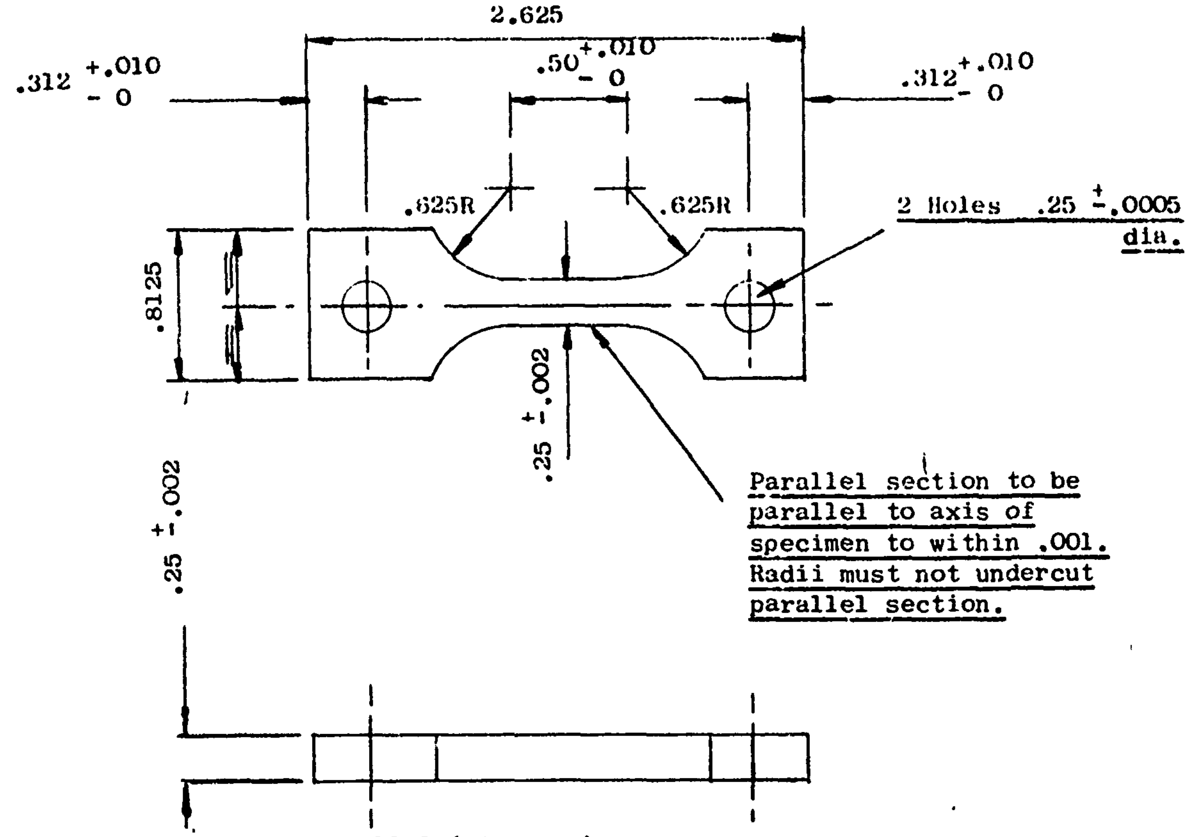

Fig. III : TENSILE TEST SPECIMEN

3.4.2. Test Specimens

The test specimens used were 0.25" thick spade ended type with a gauge length of 0.25" wide and 0.5" long. (See Fig. III). Before assembly, the specimens were pickled for 30 mins in chromic/sulphuric acid (method O DEF STAN 03-2) in order to produce a uniform specimen surface. The top ends of the specimens were protected with a maskant to prevent any galvanic action between the specimen and the stainless steel holder. All tests were carried out on short transverse specimens.

3.4.3. Fluid Cups

The fluids were held in contact with the specimens by means of acrylic plastic cups which were sealed around each specimen with a cold curing silicone rubber. At the start of the test, each specimen was stressed to the desired level, the appropriate bilge fluid or control solution placed in the cup and the time to failure determined. Test results are given in Table 4.

3.5. Microbiological Work: Fluid Samples

3.5.1. Identification of Species

The identification of the species listed in Table 2 was undertaken by the Commonwealth Mycological Institute at Kew.

3.5.2. <u>Change in Population During Corrosion Using Natural Bilge Fluids.</u>

There have been reported occasions where bacteria played an important role in the corrosion process.[2] It was decided to monitor microbiological populations before and after a corrosion test in order to evaluate possible microbiological participation in the corrosion processes occurring in the particular environments being studied. The corrosion test used was that described in para 3.1. Immediately before the corrosion test, a portion of the fluid was plated out on to nutrient agar (N.A.), incubated at 30^{o}C for 3 days and counted for total microbiological population. This was repeated at the end of the test period (7 days). Results are detailed in Table 3.

3.5.3. <u>Inoculation Tests on Synthetic Fluids.</u>

Synthetic corrodent fluids (1 gl^{-1} NaCl) were inoculated with the following species, both individually and mixed :-

1. <u>Neisseria flava</u>
2. <u>Bacillus megaterium</u>
3. <u>Pseudomonas fluorescens</u>
4. <u>Serratia marcescens</u>

A nutrient consisting of 10 g beef extract, 10 g of glucose and 3 g of tryptose per litre was added, and this mixture used as the corrodent fluid on a vibrating corrosion test (method para 3.1.) Nutrient agar plate counts were taken before and after the test to assess the behaviour of the organisms, together with pH and weight changes. Results are detailed in Table 3.

4. DISCUSSION OF TEST RESULTS

4.1. Analysis and Corrosion Test Behaviour of the Bilge Fluids: Table 1.

Generally the bilge fluids examined were found to be less corrosive than expected from their composition and particularly with respect to chloride levels. Control tests with synthetic corrodents (Table 5) produced much more corrosion at equivalent chloride levels. See Fig. IV. Only one sample, No.43, gave a higher weight loss than the control solution at an equivalent chloride level. Bilge fluids markedly less corrosive than expected were Nos. 8, 17, 35, 37, 51 and 65. Sample 65 was found to contain an anti-freeze mixture of glycols with an amine inhibitor and samples 35 and 37 were found to contain oil. Both of these materials are known to act as corrosion inhibitors under certain circumstances. Sample 8 was found to contain chromate, another known inhibitor for aluminium alloy systems, but no absolute explanation can be offered for the behaviour of samples Nos. 17 and 51 (but see later in 4.3.). Many cases of high weight loss can be directly related to chloride level, e.g. samples No.14, 38, 79, 85. Sample No.54 can be related to low initial pH and sample No.43 was found to be accompanied by a large increase in microbiological activity.

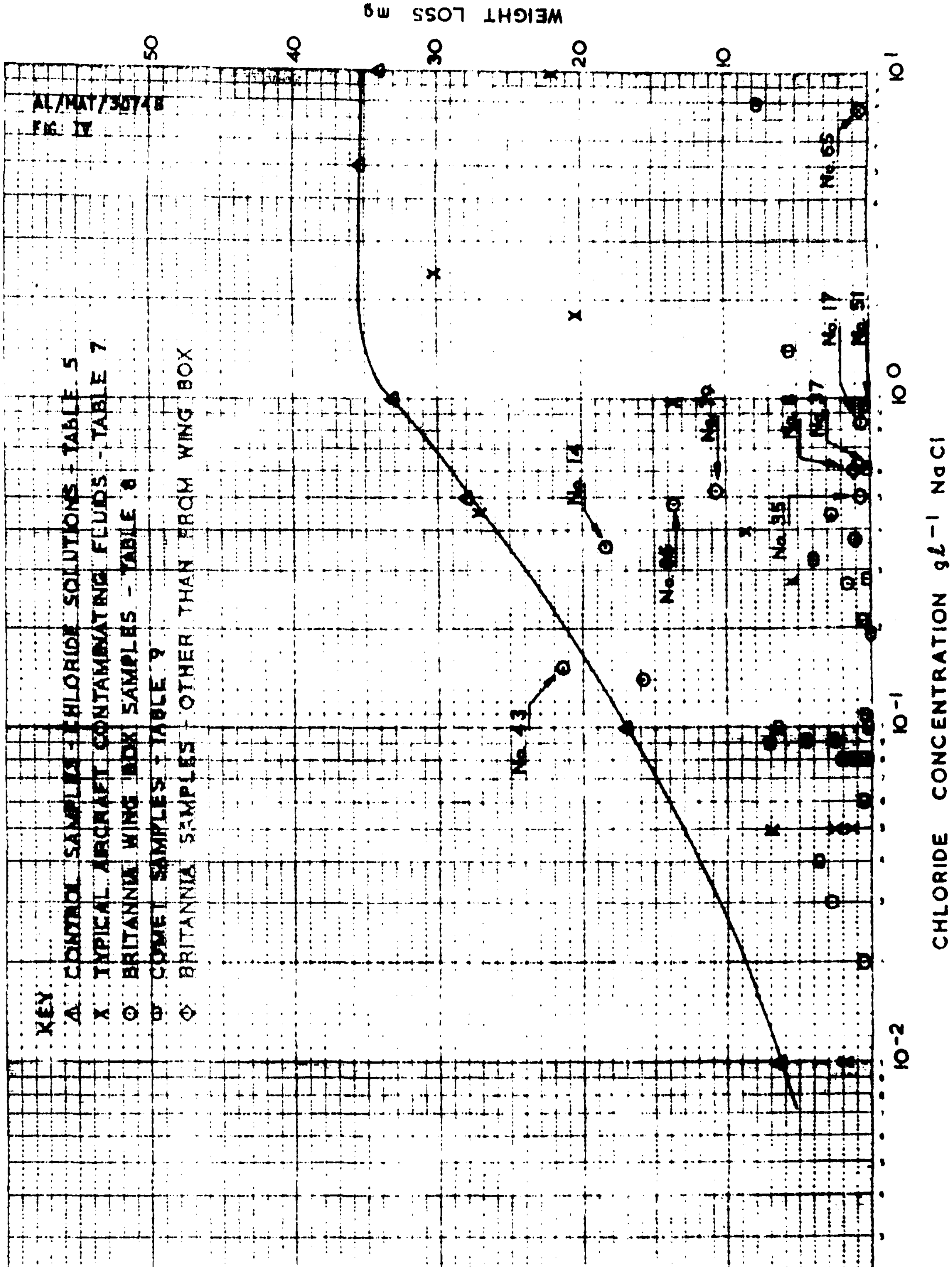

FIG. IV CHLORIDE CONCENTRATION GL^{-1} NaCl

vs WEIGHT LOSS

4.2. Correlation Between Airframe Corrosion and Corrosion Test Behaviour

Examination of the bilge fluid results listed in Table 1 revealed the following :-

4.2.1. Britannia Aircraft.

Bilge fluid samples taken from the centre wing box of Britannia aircraft generally gave significantly higher corrosion weight losses than samples from other areas of this aircraft; see Table 8.

TABLE 8

BRITANNIA WING BOX SAMPLES

Sample No.	Weight Loss (mg)	NaCl gl^{-1}	pH
14	18.3	0.35	7.2
32	12.4	-	4.15
36	0.2	0.02	6.0
43	21.1	0.15	6.6
44	2.8	0.03	7.5
54	16.7	0.14	3.6
59	1.5	0.27	4.5
68	2.8	0.44	6.9
78	1.9	0.08	5.6
81	1.0	0.37	6.35
85	13.8	0.48	5.7
Average	8.4	0.23	5.8

The average weight loss was 8.4 mg. and chloride level 0.23 gl^{-1} compared with an average weight loss over 20 samples taken from the rear freight bay of 2.1 mg. and from other areas also 2.1 mg. Chloride levels from these areas averaged 0.74 gl^{-1} as NaCl, or discounting the abnormally high samples No. 65, 80, 82, 84, averaged 0.27 gl^{-1} NaCl.

4.2.2. Comet Aircraft

No fluid from a Comet aircraft gave a weight loss higher than 8 mg., i.e. the approximate weight loss given by a 0.01 gl^{-1} NaCl solution on Table 5, but chloride levels found ranged up to 8.0 gl^{-1} NaCl. Chromate bags are used extensively in bilge areas of Comet aircraft, but chromium was not always detected in the bilge fluid. The average weight loss over 21 samples was 2.3 mg. Little correlation was evident between the sample composition, location within the aircraft and corrosion behaviour; see Table 9.

TABLE 9

COMET SAMPLES

Sample No.	Weight Loss (mg)	Position	Cr ppm	NaCl gl^{-1}	pH	Approximate Weight Loss Expected Based Upon NaCl Concentration.
19	7.4	ESB	>0.1	8.0	6.6	35
22	7.0	ESB	Nil	0.09	5.5	17
23	6.4	HY	P	0.10	5.05	17
28	0.6	RFB	Nil	0.06	6.85	10
29	4.6	RFB	>0.1	0.09	5.45	17
30	3.9	RFB	Nil	0.32	5.2	25
31	0.1	RFB	12.5	0.08	6.25	17
34	0.4	HY	-	-	6.7	-
37	0	RFB	Nil	0.60	5.4	30
47	3.7	RFB	Nil	0.04	4.15	8
48	0.1	RFB	4.7	0.10	7.2	17
49	1.1	RFB	Nil	0.08	6.2	17
50	2.8	SB	Nil	0.10	5.3	17
51	0.2	FFB	Nil	0.95	6.9	35
52	2.5	ASB	Nil	0.09	3.95	17
53	2.2	ESB	Nil	-	4.6	-
57	5.4	HY	5.8	1.40	6.0	35
70	0	RFB	1.0	0.28	6.9	25
71	0.2	RFB	Nil	0.21	6.75	20
87	0	RFB	5.8	0.20	7.25	20
89	0.4	RFB	Nil	0.11	4.1	17
Average	2.3					

KEY: ASB - Aileron Servodyne Bay.
FFB - Forward Freight Bay.
ESB - Elevator Servodyne Bay.
HY - Hydraulics Bay.
RFB - Rear Freight Bay.
SB - Servodyne Bay
P - Present

4.3. Test Work on some Aircraft Contaminating Fluids; Table 7.

The aircraft fluids selected included cleaning fluids, beverages and toilet fluids. The following facts were noted :-

1. The fluids tended to be more corrosive than bilge fluids and corresponded more nearly to the synthetic chloride corrodents; see Fig. IV. High weight losses obtained with beverages associated with galley areas, and materials associated with toilet areas, e.g. urine and toilet fluids, confirmed that these areas are likely to be highly vulnerable towards corrosion.

2. The introduction of an inert flocculent material (cellulose pulp) decreased the corrosion weight loss obtained with chloride solutions, i.e. comparing F4 and F5 in Table 7 with the equivalent solutions in Table 5. This may be a contributing factor towards the inhibition shown by the bilge fluids since many contained such materials, e.g. bilge fluid No.51.

4.4. Reduced Oxygen Level Tests; Table 6

The results detailed in Table 6 indicated that the nature of the corrosion product changed upon reducing the oxygen level in the corrodent solution, with a resulting black relatively adherent uniform deposit which was difficult to remove. Weight losses were found to be relatively independent of chloride levels and very markedly affected by the addition of chromate - much more so than with fully aerated solutions. This black corrosion product has also been observed under carpet samples used in sandwich corrosion tests. Its nature was not determined.

4.5. Stress Corrosion Tests; Table 4

All fluids gave results of a similar order when tested at 90% of the proof stress with the VAAS 554 (Al/Cu) specimens tending to give the rather longer lives. When tested at 60% of the proof stress the DTD.5050 (Al/Zn) specimens gave slightly increased lives in contact with some bilge fluids. VAAS 554 specimens showed greatly increased lives at 60% proof stress with the exception of those in contact with Fluid 65 (high chloride, low weight loss). See Figs. Va and Vb.

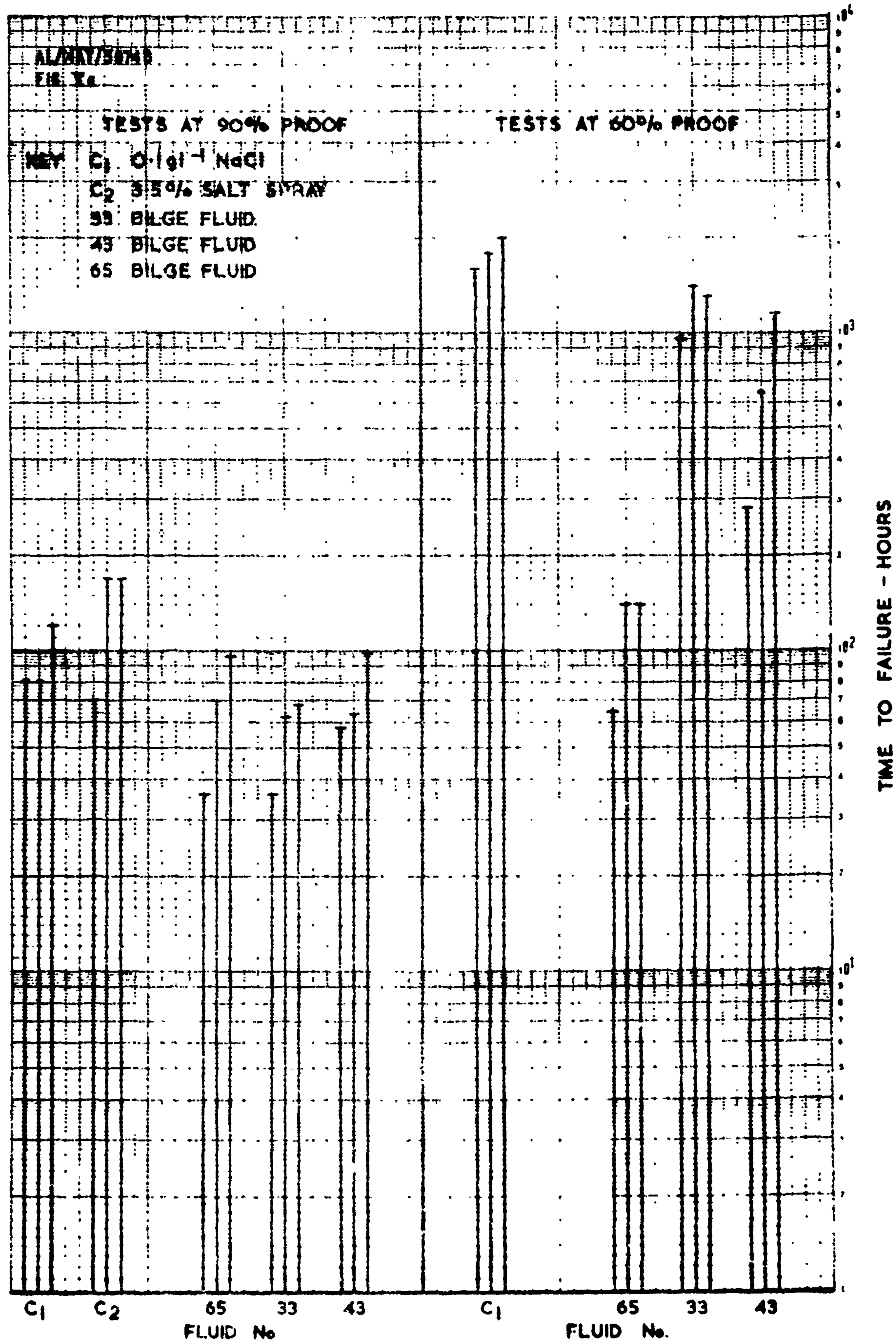

FIG. Va STRESS CORROSION TESTS - VAAS. 554 SPECIMENS

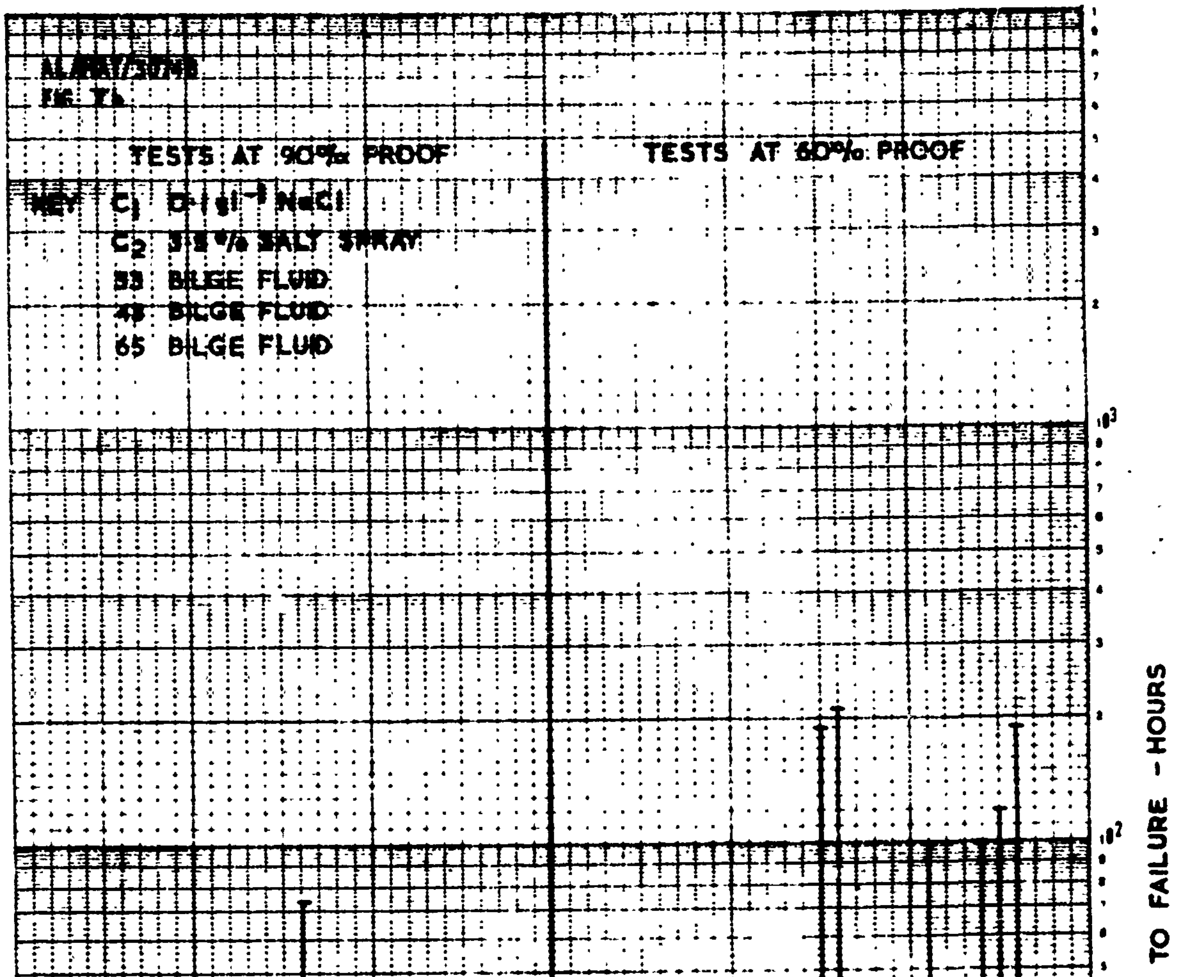

FIG. Vb STRESS CORROSION TESTS - DTD. 5050 SPECIMENS

4.6. Microbiological Work

4.6.1. Microbiological Identifications, Table 2.

The microbiological species listed in Table 2 include species which have previously been identified[2] as capable of assisting corrosion under the appropriate conditions. These were Achromobacter, Micrococcus, Pseudomonas, Bacillus and Flavobacterium, all being species of bacteria. In addition, a fungus Cladosporium sp. and various species of yeasts were identified. Generally the majority of species identified were bacteria and were randomly distributed throughout the aircraft. It should be noted that the microbiological species identified were those typically found in many environments, and that the quantities found were considered also to be fairly typical. Areas immediately in the vicinity of toilets were found to be relatively sterile, presumably due to disinfectant measures.

4.6.2. Microbiologically Assisted Corrosion; Table 3

Of the bilge fluids monitored for microbial activity during corrosion, four gave quite large weight losses. In two cases (Fluids 54 and 57), this weight loss might be attributed to high acidity and chloride levels respectively. During the corrosion test, the total microbial populations in these two samples fell to almost zero, indicating little participation in the corrosion process. Samples 43 and 60 exhibited growths in microbial populations, and analysis gave only moderate chloride levels and almost neutral pH values, indicating possible microbial participation. This led to a further investigation on synthetic fluids 28/2 to 28/6) which were inoculated with various species of bacteria as shown in Table 3. During the test period negligible corrosion occurred and, considering the high initial chloride levels, these fluids appeared to be remarkably inhibited. However, large increases in microbial populations occurred. Further work would be required to fully investigate the implications of these results, but the presence of phosphates and other potential inhibitors in the nutrients (including soups and broths) possibly affects the corrosion rate.

4.7. Special Investigations

The two cases of pitting corrosion reported in paras 3.2.1. and 3.2.2. were of a similar nature.

4.7.1. Corrosion of the DTD.5020, fully pretreated and painted machined floor panels (para 3.2.1.) had occurred around an area adjacent to the galley. The area was covered with a carpet/foam underlay system. Analysis of the aqueous extracts from the carpet (3.2.1.2.) gave high chloride figures, but negligible corrosion was obtained using this extract as the corrodent in the laboratory corrosion test (para 3.1.) The carpet test (para 3.2.1.4.) was performed in order to assess local environmental effects. In the aircraft the carpet/underlay system obviously retains any fluid spillage for a relatively long period. Spillage from the galley will leach chloride from the carpet in addition to being itself a source of corrodents. Initially, and to produce an effect within a reasonably short period, the test panels used were unpainted and, as reported in para 3.2.1., 0.030" of corrosion was produced under the aircraft carpet sample in 63 days. The weight loss of these panels when represented as a fraction of the total weight of the panels is very small, but in structural terms severe corrosion has been produced. This illustrates the difficulty in assessing this type of corrosion in numerical terms and indicates the shortcomings of weight loss measurements.

4.7.2. The investigation into a second example of floor corrosion (para 3.2.2.) again illustrated the environmental aspects relating to corrosion. Area 1 in Fig.I is directly underneath the galley and is a fully painted open structure. No corrosion had occurred but there was abundant evidence of galley spillage. Area 2 is in front of the galley and was painted to the same standard. This was overlaid with a PVC/glasscloth laminate, which is essentially non-absorbent. The paint had been removed, presumably by physical action, but no corrosion had occurred although the metal surface contained evidence of dried liquid-borne contaminants. Area 3 was located immediately inside the passenger compartment. The paint system was virtually intact except for blistered areas which contained fairly deep pitting corrosion. This area is covered by a foam underlay/carpet system. The test, reported in para 3.2.2., attempted to reproduce these conditions, using fully painted panels, and succeeded in removing paint from under the Area 2 simulation. The Area 3 situation did not produce any corrosion in the test period (3 months), but the paint finish did become stained. With reference to the carpet tests reported above, it is reasonable to suppose that once the paint film becomes broken or porous, pitting corrosion will occur.

The influence, or otherwise, of microbial participation in pitting corrosion under these circumstances was not proven.

5. GENERAL DISCUSSION

5.1. Airframe Corrosion: Background Information

The aim of this activity was to obtain as much information as possible relating to the corrosion behaviour of the aircraft types under investigation. Information was obtained both by visual observation and by consultation. The former activity tended to be limited to the structure available for inspection as dictated by the service schedule, and often yielded comparatively little information. However, many of the aircraft involved in the programme also featured in a Central Servicing Design Establishment (C.S.D.E.) Report (No.R3/68) on corrosion in keel areas of Royal Air Force aircraft, and discussions with C.S.D.E. revealed that many of the aircraft types involved in the programme had suffered corrosion damage as detailed in this report.

5.2. It has been noted during examination of aircraft, both in this programme and previously with earlier aircraft, that the pattern of corrosion has tended to vary with the type of protection used at manufacture. Aircraft of the Britannia/Comet/Viscount period suffered corrosion of skins, primarily at lap joints in the vicinity of toilets and galley areas, which sometimes necessitated structural replacements.

5.3. Later aircraft, e.g. VC-10, used improved sealants and paint systems and to date little corrosion has been experienced within joints. Where corrosion has occurred it is more usually associated with the juxtaposition of materials, notably where absorbent coverings are placed in contact with fully painted areas. Where such a combination is frequently wetted, breakdown of the paint film sometimes occurs by a blistering mechanism, followed by corrosion of the underlying or exposed metal. In such circumstances, if it is not possible to isolate the painted metal by, for example, a self-adhesive plastic film, the use of a more permeable paint system such as a primer only system may be of benefit.

6. CONCLUSIONS

6.1. During this investigation into the corrosion properties of airframe contaminants, 64 samples collected from various aircraft were chemically examined and subjected to corrosion tests using some typical aircraft aluminium alloys.

Assessment of corrosivity was by a weight loss measurement. Weight losses were compared with results from a similar number of tests performed using synthetic (mainly chloride) corrodents, some typical aircraft fluids and blank solutions. This comparison revealed that at equivalent contaminant levels (chloride, pH etc.), the airframe bilge fluids showed considerable inhibition, but the corrosivity of the aircraft contaminating fluids was much as expected. In some cases the inhibition was explained by the presence of known inhibitors (chromate and nitrogenous bases etc.), but generally the inhibition was unexpected.

Stress corrosion tests did not produce similar inhibitions. At the 90% proof stress level, all specimens showed similar times to failure, indicating that at this stress level, test parameters other than stress have little influence. At the 60% proof stress level, variations between test fluids and control fluids were found. DTD.5050 (Al/Zn alloy) generally exhibited inhibition with the test fluids relative to control fluids, Fig. Vb, but VAAS 554 (Al/Cu) specimens, Fig. Va, generally gave shorter lives for the test fluids relative to control fluids. Overall the VAAS 554 alloy was found to be less susceptible to stress corrosion cracking than DTD.5050.

6.2. It would appear that, close to their source, fluids are potentially relatively corrosive, and in travelling to bilge areas, assisted in their passage by condensate, they accumulate solids, oils and greases and inhibitors, such as chromate, which progressively decrease their corrosivity. Some correlation was obtained between the behaviour of certain fluids and their location within the aircraft. In particular, the wing box area of Britannia aircraft was shown to be exposed to a potentially higher risk of corrosion from bilge fluid contamination than some other areas of this aircraft.

6.3. Generally, however, most corrosion which can be directly ascribed to the presence of particular corrodents is likely to occur in the vicinity of the source of these corrodents; i.e. near galley and toilet areas and areas where spillages may occur, e.g. battery bays. In other areas, e.g. floor areas, the nature of the fluid probably has less influence than other factors such as materials combination and lack of adequate protection. Chromate appears from test results to be particularly beneficial in areas where oxygen supply is limited, e.g. crevices. Results of microbiological work undertaken in the programme did not indicate that the presence of microbiological species automatically led to increased corrosion. However, it is probable that under favourable conditions some contribution from such agents occurs as has been demonstrated in aircraft fuel tanks and reported elsewhere.[3] Simulation of these conditions in laboratory experiments designed to isolate the specific effects of microbiological species is outside of the scope of this programme.

REFERENCES

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TABLE 1

BILGE FLUIDS : ANALYSIS AND CORROSION TEST RESULTS

Sample No.	Location	Sampled By	A/C No.	A/C Type	pH	Oil	Suspended Solids v/v	Fe	Cr ppm	Al	Na_2SO_4	NaCl gl^{-1}	Weight loss mg. Static 3 wk.	Weight loss mg. 1 week Vibrating	Sample No.
1	No. 2 Nacelle	BAC	XL660	Britannia	7.0	Nil	1%	Nil	Nil	Nil	P	0.12	0.2	0.3	1
2	No. 3 Nacelle	BAC	XL660	Britannia	6.9	T	2%	Nil	Nil	Nil	Nil	0.10	0.0	0.4	2
8	Front of rear freight bay	BAC	XL660	Britannia	7.6	Nil	1%	Nil	1.5	Nil	P	0.60	0.2	0.6	8
11[+1]	Front of Cabin area	BAC	XV192	Hercules	-	100%	Nil	-	-	-	-	-	-	-	11
12	Ramp Floor	BAC	XV192	Hercules	7.95	Nil	2%	Nil	0.2	Nil	T	0.16	0.1	0.5	12
14	Wing Box	RAF	XN404	Britannia	7.2	T	1%	Nil	Nil	Nil	T	0.35	3.2	18.3	14
17	Forward Freight Bay	BAC	XN404	Britannia	7.25	Nil	Nil	Nil	Nil	Nil	P	0.84	1.6	0.7	17
19	Elevator Servodyne Bay	RAF	XR396	Comet	6.6	Emulsion	-	Nil	> 0.1	P	P	8.0	0.8	7.4	19
20	Rear Freight Bay	RAF	XM496	Britannia	7.1	Nil	Trace	Nil	1.5	Nil	Nil	0.11	0.2	0.4	20
21	Front of Rear Freight Bay	RAF	XM496	Britannia	6.6	Nil	1%	Nil	Nil	Nil	Nil	0.08	0.4	0.6	21
22	Elevator ServodyneBay	RAF	XR395	Comet	5.5	P	30%	Nil	Nil	T	T	0.09	0.7	7.0	22
23	Hydraulic Bay	RAF	XR395	Comet	5.05	Emulsion	-	Nil	P	T	Nil	0.10	2.2	6.4	23
28	Rear Freight Bay	BAC	XR397	Comet	6.65	Nil	1%	Nil	Nil	Nil	T	0.06	-	0.6	28
29	Rear Freight Bay	BAC	XR397	Comet	5.45	Emulsion	-	Nil	> 0.1	T	T	0.09	-	4.6	29
30	Rear Freight Bay	BAC	XR397	Comet	5.2	Emulsion	-	Nil	Nil	T	Nil	0.32	-	3.9	30
31	Rear Freight Bay	RAF	XR397	Comet	6.25	Nil	T	Nil	12.5	Nil	T	0.08	-	0.1	31
32	Wing Box	RAF	XM496	Britannia	4.15	T	10%	-	-	Nil	P	-	-	12.4	32
33	Front of Rear Freight Bay	RAF	XM496	Britannia	7.3	Nil	T	Nil	Nil	Nil	P	0.35	-	4.5	33
34	Hydraulic Bay	RAF	XR399	Comet	6.7	Emulsion	2-3%	-	-	Nil	Nil	-	-	0.4	34
35	Front of Rear Freight Bay	RAF	XM497	Britannia	6.3	T Emulsion	2-3%	Nil	Nil	Nil	Nil	0.50	-	0.5	35
36	Wing Box	RAF	XM497	Britannia	6.0	Nil	1%	Nil	Nil	Nil	Nil	0.02	-	0.2	36
37	Rear Freight Bay	RAF	XR398	Comet	5.4	Emulsion	-	Nil	Nil	Nil	Nil	0.6	-	0.0	37

TABLE 1 (Contd.)

BILGE FLUIDS: ANALYSIS AND CORROSION TEST RESULTS

Sample No.	Location	Sampled By	Aircraft No.	Aircraft Type	pH	Oil	Suspended Solids v/v	Fe	Cr ppm.	Al	Na_2SO_4 gl^{-1}	NaCl gl^{-1}	Δ pH during Corrosion	Weight loss mg. 1 week vibrating	Sample No.
38	Station 3/9	R.A.F.	XV103	VC.10	7.8	Nil	1%	Nil	Nil	Nil	0.46	0.82	–	24.0	38
39	Front of Rear Freight Bay	R.A.F.	XM496	Britannia	8.1	Nil	< 1%	Nil	0.80	Nil	Nil	0.18	+0.01	0.4	39
40	Rear Freight Bay	R.A.F.	XL660	Britannia	8.3	Nil	< 1%	Nil	1.15	Nil	Nil	0.175	+0.13	0.5	40
41	Rear Freight Bay	R.A.F.	XN404	Britannia	7.6	[illegible]	< 1%	Nil	1.45	Nil	Nil	0.31	+0.87	0.2	41
42	Front of Rear Freight Bay	R.A.F.	XM496	Britannia	8.1	Nil	< 1%	Nil	0.67	Nil	0.19	0.39	+0.66	1.5	42
43	Wing Box	R.A.F.	XM496	Britannia	6.8	Emulsion	2 - 3%	Nil	0.10	T	T	0.15	+2.11	21.1	43
44	Wing Box	R.A.F.	XM497	Britannia	7.5	Nil	< 1%	Nil	0.05	Nil	Nil	0.03	+0.82	2.3	44
45	Front of Rear Freight Bay	R.A.F.	XM497	Britannia	7.6	Nil	5%	Nil	0.63	Nil	0.24	0.31	+1.35	0.4	45
46*2		R.A.F.			9.6	100%	Nil	Nil		Nil	T	-	-0.05	0.0	46
47	Rear Freight Bay	R.A.F.	XR394	Comet	4.15	T	Nil	Nil	Nil	Nil	Nil	0.04	+1.80	3.7	47
48	Rear Freight Bay	R.A.F.	XR398	Comet	7.2	Nil	< 1%	Nil	4.7	Nil	0.11	0.10	+1.75	0.1	48
49	Rear Freight Bay	R.A.F.	XR396	Comet	6.2	T	Nil	Nil	Nil	Nil	Nil	0.08	+2.10	1.1	49
50	Rear Servodyne Bay	R.A.F.	XR396	Comet	5.3	5%	Nil	Nil	Nil	T	Nil	0.10	+2.20	2.8	50
51	Forward Freight Bay	R.A.F.	XR396	Comet	6.9	Nil	10%	Nil	Nil	Nil	Nil	0.95	+1.80	0.2	51
52	Aileron Servodyne Bay	R.A.F.	XR396	Comet	3.95	T	Nil	Nil	Nil	T	Nil	0.09	-0.45	2.5	52
53	Elevator Servodyne Bay	R.A.F.	XR396	Comet	4.6	T	Nil	Nil	Nil	Nil	Nil	-	+2.20	2.2	53
54	Wing Box	R.A.F.	XL660	Britannia	3.6	T	2%	Nil	Nil	Nil	Nil	0.14	+3.70	16.7	54
55	Front of Rear Freight Bay	R.A.F.	XL660	Britannia	7.9	T	5%	Nil	1.87	Nil	Nil	0.15	+0.60	0.1	55
56	Front of Rear Freight Bay	R.A.F.	XN404	Britannia	7.1	Nil	5%	Nil	1.0	Nil	Nil	0.145	+1.30	0.6	56
57	Under Hydraulic Bay	R.A.F.	XR396	Comet	6.0	T	Emulsion	Nil	5.8	T	Nil	1.41	+1.80	5.4	57
59	Wing Box	R.A.F.	XL660	Britannia	4.5	T	1 - 2%	Nil	Nil	Nil	0.36	0.27	+2.30	1.5	59
60	Rear Freight Bay	R.A.F.	XL666	Britannia	7.1	Nil	1 - 2%	Nil	0.24	Nil	Nil	0.24	+1.10	10.6	60
61	Front of Rear Freight Bay	R.A.F.	XL666	Britannia	7.3	Nil	1%	Nil	0.15	Nil	Nil	0.15	+1.20	0.3	61
65	Front of Rear Freight Bay	B.A.C.	XM497	Britannia	6.3	Nil	1%	Nil	Nil	Nil	Nil	7.29	+1.65	0.6	65
66	Front of Rear Freight Bay	B.A.C.	XM497	Britannia	7.0	Nil	-	-	Nil	-	-	-	+0.15	0.7	66
68	Wing Box	R.A.F.	XN404	Britannia	6.9	Nil	1%	Nil	Nil	Nil	0.33	0.445	+1.45	2.8	68
69	Front of Rear Freight Bay	R.A.F.	XN404	Britannia	7.7	Nil	T	Nil	Nil	Nil	Nil	0.06	+0.70	3.4	69
70	Front of Rear Freight Bay	B.A.C.	XR398	Comet	6.9	Nil	2%	Nil	1.0	Nil	Nil	0.28	+1.30	0.0	70
71	Front of Rear Freight Bay	B.A.C.	XR398	Comet	6.75	Nil	2%	Nil	Nil	Nil	Nil	0.21	+1.80	0.2	71
75	Front of Rear Freight Bay	R.A.F.	XN404	Britannia	7.2	Nil	T	Nil	0.4	Nil	Nil	0.08	+1.20	0.8	75
76*3	Forward Freight Bay	R.A.F.	XN404	Britannia	-	75%	Emulsion	Nil	-	Nil	T	-	-	-	76
77	Front of Rear Freight Bay	R.A.F.	XM496	Britannia	5.6	Nil	Cloudy	Nil	Nil	Nil	0.28	0.32	+2.30	0.0	77

TABLE 1 (Contd.)

BILGE FLUIDS: ANALYSIS AND CORROSION TEST RESULTS

Sample No.	Location	Sampled By	Aircraft No.	Aircraft Type	pH	Oil	Suspended Solids	Fe	Cr p.p.m.	Al	Na_2SO_4 gl^{-1}	NaCl gl^{-1}	PO_4^{3-}	NO_3^-	Total Solids gl^{-1}	Δ pH During Corrosion	Weight Loss Corrosion mg.	Sample No.
78	Wing Box	R.A.F.	XL660	Britannia	5.6	Nil	T	Nil	Nil	Nil	Nil	0.08	Nil	Nil	0.7	-	1.9	78
79	Front of Rear Freight Bay	R.A.F.	XL660	Britannia	7.3	Nil	T	Nil	Nil	Nil	Nil	0.51	Nil	Nil	1.5	-	10.9	79
80	Rear Freight Bay	R.A.F.	XL660	Britannia	6.9	Nil	T	Nil	0.6	Nil	Nil	1.01	Nil	Nil	2.2	-	1.9	80
81	Wing Box	R.A.F.	XM497	Britannia	6.35	Nil	T	Nil	Nil	Nil	Nil	0.37	Nil	Nil	1.2	-	1.0	81
82	Front of Rear Freight Bay	R.A.F.	XM491	Britannia	8.05	Nil	2%	Nil	Nil	Nil	T	2.58	Nil	Nil	4.9	-	5.3	82
84	Under Flap Motor	R.A.F.	XL635	Britannia	8.3	Nil	T	Nil	0.6	Nil	T	1.545	Nil	Nil	2.9	-	6.7	84
85	Wing Box	R.A.F.	XM491	Britannia	5.7	Nil	1%	Nil	Nil	Nil	T	0.48	Nil	Nil	1.5	-	13.8	85
87	Rear Freight Bay	B.A.C.	XR395	Comet	7.25	Nil	T	Nil	5.8	Nil	Nil	0.20	Nil	Nil	-	+0.35	0	87
88	Servodyne Bay	B.A.C.	XR398	Comet	4.75	Nil	T	P	Nil	P	P	0.23	Nil	T	-	-	-	88
89	Rear Freight Bay	B.A.C.	XR398	Comet	4.1	Nil	T	P	Nil	Nil	P	0.11	Nil	T	-	+1.7	0.35	89

NOTES :
- *1 Diester Oil
- *2 Lockheed Hydraulic Fluid
- *3 D.T.D. 585

KEY:
- T Trace Level
- P Present

Remarks: 1. Phosphate was not detected in any fluid.

TABLE 2

MICROBIOLOGICAL EXAMINATION OF BILGE FLUID SAMPLES

Sample No.	IMI No.	Type	Name of Organism	Approx. Count cells/ml.	Location	Sample Type	A/C No.	A/C Type	Sample No.
3	B.4092	Yeast	Torulopsis famata	1.45×10^3	Lower Fuselage Wall under Toilet	Swab	XL660	Britannia	3
4	B.4083	Bacteria	Micrococcus sp.	10	Toilet Drain Pipe	Swab	XL660	Britanria	4
5	B.4094	"	Pseudomonas sp.	3.1×10^4	Fuselage Bilge Area Under Toilet & Galley	Liquid	XL660	Britannia	5
	B.4095	"	Pseudomonas sp. similar to B.4094	2.2×10^4					
	B.4096	"	Pseudomonas sp. (or possibly Protaminobacter ruber)	1.3×10^4					
	B.4097	"	Flavobacterium sp.	1.1×10^4					
	B.4098	"	Flavobacterium sp. different from B.4097	6×10^3					
6	B.4099	"	Achromobacter sp.	10	Top of Toilet Box	Swab	XL660	Britannia	6
	B.4100	"	Bacillus megaterium.	20					
	B.4101	"	Bacillus sp cereus group	10					
7	B.4103	"	Corynebacterium sp.	4.5×10^4	Galley Top	Swab	XL660	Britannia	7
	B.4104	"	Pseudomonas sp.	9×10^3					
	B.4105	"	Pseudomonas putida	6×10^3					
	B.4106	Yeast	Hansenula subpelliculosa	6×10^3					
	B.4107	Bacteria	Micrococcus conglomeratus	500					
	B.4108	"	Flavobacterium sp.	400					
	B.4109	Yeast	Rhodotorula sp.	400					
13	B.4151	Yeast Fungus	One yeast in small numbers. Gross mixture of fungal growths	–	Galley Top	Swab	XV192	Hercules	13
15	B.4214	Bacteria	Achromobacter sp.	7.5×10^5	Visible Growth on Webbing in Freight Bay	Swab	XN404	Britannia	15
	B.4215	"	Flavobacterium sp.	3.7×10^5					
	B.4216	"	Brevibacterium sp.	7.5×10^4					
	B.4217	Yeast	–	5×10^4					
	B.4218	Bacteria	Flavobacterium sp.	2.5×10^4					
17	B.4208	"	Alcaligenes faecalis	1.2×10^5	Forward Freight Bay	Liquid	XN404	Britannia	17
	B.4209	"	Achromobacter eurydice	2×10^4					
	B.4210	"	Flavobacterium sp.	4.5×10^4					
	B.4211	"	Flavobacterium sp. similar to B.4210	–					
	B.4214	"	Protaminobacter ruber	1×10^4					
18	B.4219	Yeast	Probably Rhodotorula sp.	6×10^3	Rear Freight Bay Wall under Toilet	Swab	XN404	Britannia	18
	B.4220	Yeast	Probably Torulopsis sp.	4×10^3					
	B.4221	Bacteria	Bacillus sp.	20					

TABLE 2 (Cont'd.)

Sample No.	IMI No.	Type	Name of Organism	Approx. Count cells/ml.	Location	Sample Type	A/C No.	A/C Type	Sample No.
26	B.4256	Bacteria	Flavobacterium sp.	1.9×10^4	Forward Freight Bay	Swab	XR397	Comet	26
	B.4257	"	Brevibacterium sp.	3×10^3					
	B.4258	"	Achromobacter sp.	6×10^3					
	B.4259	"	Achromobacter sp. similar to B.4258	2.5×10^4					
	B.4260	"	Protaminobacter ruber	2×10^4					
27	B.4270	Yeast	Rhodotorula sp.	8.3×10^4	Forward Freight Bay	Swab	XR397	Comet	27
28	B.4261	Bacteria	Pseudomonas sp.	3.6×10^5	Rear Freight Bay	Liquid	XR397	Comet	28
	B.4262	"	Pseudomonas fluorescens	8×10^4					
	B.4263	"	Pseudomonas fluorescens similar to B.4262	8×10^4					
29	B.4264	"	Pseudomonas sp. similar to B.4261	4×10^5	Rear Freight Bay (Adjacent to, but separate from 28)	Liquid	XR397	Comet	29
	B.4265	"	Pseudomonas sp. similar to B.4261	2×10^5					
	B.4266	"	Flavobacterium sp	3.5×10^3					
	B.4269	Yeast	Rhodotorula sp.	1.6×10^5					
	B.4271	Bacteria	Pseudomonas fluorescens (appears identical to B.4263)	5×10^5					
30	B.4267	.	Pseudomonas fluorescens (appears identical to B.4263)	6×10^5	Rear Freight Bay (Adjacent to but separate from 28 & 29)	Liquid	XR397	Comet	30
	B.4268	"	Pseudomonas fluorescens	5×10^3					
62	B.4367	"	Bacillus megaterium	6×10^3	Below Rear Galley	Sterile Swab	XM496	Britannia	62
		"	Bacillus coagulans	1×10^3					
		"	Pseudomonas putida	3×10^3					
		Yeast	—	3×10^3					
		Fungus	Cladosporium sp	Many Colonies					

TABLE 3

MICROBIOLOGICAL POPULATION CHANGES DURING CORROSION

Sample No.	Sample Description	Change in Population during Corrosion	Loss in Weight during Corrosion mg.	Change in pH during Corrosion	NaCl gl^{-1}	Initial pH	Location	Aircraft Type	Aircraft No.	Sample No.
39	Bilge Fluid	$+9.7 \times 10^5$	0.4	+0.01	0.18	8.10	Front of Rear Freight Bay	Britannia	XM496	39
41	" "	$+9.4 \times 10^4$	0.2	+0.9	0.31	7.60	Rear Freight Bay	Britannia	XN404	41
42	" "	-1.6×10^5	1.5	+0.7	0.39	8.14	Front of Rear Freight Bay	Britannia	XM496	42
43	" "	$+9.4 \times 10^8$	21.1	+2.1	0.15	6.61	Wing Box	Britannia	XM497	43
44	" "	-2.4×10^6	2.8	+0.8	0.03	7.47	Wing Box	Britannia	XM497	44
54	" "	-2.1×10^5*	16.7	+3.7	0.14	3.63	Wing Box	Britannia	XL660	54
55	" "	$+2.8 \times 10^3$	0.1	+0.6	0.15	7.93	Front of Rear Freight Bay	Britannia	XL660	55
56	" "	$+2.5 \times 10^6$	0.6	+1.3	0.15	7.10	Front of Rear Freight Bay	Britannia	XN404	56
57	" "	-3.1×10^6*	5.4	+1.8	1.41	5.97	Under Hydraulic Bay	Comet	XR396	37
59	" "	-1.7×10^6	1.5	+2.3	0.27	4.48	Wing Box	Britannia	XL660	59
60	" "	$+3.0 \times 10^6$	10.6	+1.1	0.24	7.13	Rear Freight Bay	Britannia	XL660	60
61	" "	$+6.0 \times 10^5$	0.3	+1.2	0.15	7.28	Front of Rear Freight Bay	Britannia	XL660	61
S28/2	0.1% NaCl + Nutrient (N)	-2.4×10^8	1.4	-0.65	1.0	6.05	-	-	-	S28/2
S28/3	0.1% NaCl + N + *Neisseria flava*	$\gg 3 \times 10^8$	0.8	+0.35	1.0	6.05	-	-	-	S28/3
S28/4	0.1% NaCl + N + *Bacillus megaterium*	$\gg 3 \times 10^8$	0.8	+1.75	1.0	6.05	-	-	-	S28/4
S28/5	0.1% NaCl + N + *Pseudomonas fluorescens*	$\gg 3 \times 10^8$	0.8	+3.0	1.0	5.50	-	-	-	S28/5
S28/6	0.1% NaCl + N + Mix of Above + *Serratia marcescens*	$\gg 3 \times 10^8$	0.75	+3.25	1.0	5.35	-	-	-	S28/6
B	Distilled Water Blank	-	0.64	+0.6	Nil	5.9	-	-	-	B

Key: N; 10g Beef Extract)
3g Tryptose) per litre
10g Glucose)

*Microbial Activity Ceased.

TABLE 4

BILGE FLUID STRESS CORROSION TEST RESULTS

VAAS 554 (L95) TYPE SPECIMENS				DTD.5050 (2024 T3) SPECIMENS			
90% Proof		60% Proof		90% Proof		60% Proof	
Fluid	Failure Hrs.	Fluid	Failure Hrs.	Fluid	Failure Hrs.	Fluid	Failure Hrs.
33	36 64 69	33	976 1311 1489	33	10 24 46	33	21 21 101
43	59 64 98	43	279 665 1105	43	26 35 46	43	101 125 193
65	36 71 98	65	65 137 137	65	24 24 75	65	45 193 210
0.1 gl^{-1} NaCl	81 81 117	0.1 gl^{-1} NaCl	1634 1815 1983	0.1 gl^{-1} NaCl	23 24 30	0.1 gl^{-1} NaCl	19 21 36
Acidified Salt Spray 3.5%	70 169 169	- - -	- - -	Acidified Salt Spray 3.5%	9 16 22	- - -	- - -

TABLE 5

CORROSION WEIGHT LOSSES USING SYNTHETIC CORRODENT SOLUTIONS

Sample No.	Weight Loss mg.	Average	Analysis gl^{-1}			Remarks
			NaCl	Na_2SO_4	K_2CrO_4	
A	3.1		0.01			All tests were by the vibrating method (3.1) which results in a continuously aerated solution The average blank figure (distilled water) gave a weight loss of 0.6 mg.
56	10.0		0.01			
57	7.5		0.01			
58	4.5	6.3	0.01			
59	6.8		0.01			
60	5.9		0.01			
61	6.5		0.01			
B	14.1		0.1			All tests were by the vibrating method (3.1). Repeat tests on similar solutions throughout the programme were to assess the repeatability of the method and to establish confidence levels. The blank figure was 0.6 mg. for distilled water.
1	14.7		0.1			
2	20.3		0.1			
3	20.4		0.1			
4	17.4		0.1			
5	17.7		0.1			
6	12.9		0.1			
13	16.6	17.0	0.1			
14	12.5		0.1			
15	14.5		0.1			
50	15.7		0.1			
51	15.6		0.1			
52	20.6		0.1			
53	20.2		0.1			
54	19.6		0.1			
55	14.6		0.1			
C	28.0		0.5			Results indicate that the limiting corrosion current under the test conditions results in a weight loss of approximately 35mg. The addition of sulphate appears to inhibit corrosion by a small amount
D	33.3		1.0			
E	35.4		5.0			
F	33.8		10.0			
G	17.4		0.1	0.01		
H	16.7		0.1	0.1		
I	13.8		0.1	1.0		
J	11.6		0.1	5.0		

TABLE 5 (Cont'd.)

Sample No.	Weight Loss mg	Average	Analysis gl^{-1}			Remarks
			NaCl	Na_2SO_4	K_2CrO_4	
7	8.8	8.9	0.1		0.01	These results show the effect of chromates as inhibitors.
8	11.9		0.1		0.01	
9	10.4		0.1		0.01	
10	5.4		0.1		0.01	
11	5.4		0.1		0.01	
12	11.7		0.1		0.01	

TABLE 6

CORROSION WEIGHT LOSSES USING SYNTHETIC SOLUTIONS: REDUCED OXYGEN (THUNBERG TUBES)

Sample No.	Weight Loss mg.	Average	Analysis gl^{-1}			Sample No.	Weight Loss mg.	Average	Analysis gl^{-1}		
			NaCl	Na_2SO_4	K_2CrO_4				NaCl	Na_2SO_4	K_2CrO_4
32	12.0		0.001			16	10.5		0.1		
33	12.8		0.001			17	10.9		0.1		
34	10.6		0.001			18	10.3	10.4	0.1		
35	11.6	10.7	0.001			19	10.1		0.1		
36	8.1		0.001			20	10.1		0.1		
37	9.1		0.001			44	11.4		0.2		
21	6.3		0.01			45	12.5		0.2		
22	8.2		0.01			46	13.3	12.9	0.2		
23	5.7		0.01			47	12.8		0.2		
24	5.4		0.01			48	13.8		0.2		
25	6.6	7.0	0.01			49	12.3		0.2		
26	8.5		0.01			38	1.4		0.1		0.01
27	7.2		0.01			39	1.8		0.1		0.01
28	5.7		0.01			40	1.5	1.5	0.1		0.01
29	7.2		0.01			41	1.3		0.1		0.01
30	7.2		0.01			42	1.5		0.1		0.01
31	10.1		0.01			43	1.4		0.1		0.01

REMARKS

1. These tests were performed in containers from which the air had been evacuated.
2. The corrosion product was observed to be a black adherent deposit as opposed to the more normal loosely adherent white deposits associated with aluminium corrosion.
3. When compared with test results from fully aerated solutions (Table 4), the corrosion weight losses appear to be relatively independent of chloride level.
4. The effect of chromate is much more marked than with fully aerated solutions.
5. The weight loss obtained for the blank sample was much higher than that for other tests as shown below.

Sample No.	Weight Loss mg.	Sample No.	Weight Loss mg.
8	6.9	15	5.9
9	5.3	16	7.0
10	6.4	17	6.3
11	6.2	18	6.8
12	6.0	33	9.3
13	6.2	34	8.7
14	7.2	35	8.8
		36	8.2

The average figure is 6.9 mg. compared to 0.6 mg. for the tests with unlimited

TABLE 7

ANALYSIS AND CORROSION TEST RESULTS : AIRCRAFT CONTAMINATING FLUIDS

Sample No.	Description	pH	NaCl gl^{-1}	Na_2SO_4 gl^{-1}	Cr p.p.m.	Fe p.p.m.	Al	PO_4^{3-}	Carbo-hydrate	NO_3^-	pH Change	Reducing Agent	Weight loss mg	Sample No.
F1	Coffee (White)	5.6	0.27	Nil	Nil	Nil	Nil	Nil	P	Nil	+0.6	Nil	5.6	F1
F2	1% v/v Lacine - A Chlorinating Material	10.4	1.82	Nil	Nil	Nil	Nil	Nil	Nil	Nil	-1.95	Nil	20.3	F2
F3	2% v/v Racasan - A Toilet Fluid	7.5	0.05	Nil	Nil	Nil	Nil	P	Nil	Nil	+1.6	P	1.6	F3
F4	1 gl^{-1} NaCl + 1% Cellulose	4.9	1.0	Nil	Nil	Nil	Nil	Nil	Nil	Nil	+2.5	Nil	13.7	F4
F5	10 gl^{-1} NaCl + 1% Cellulose	4.9	10.0	Nil	Nil	Nil	Nil	Nil	Nil	Nil	+3.0	Nil	22.1	F5
F6	Bitter Lemon Drink (Undiluted)	2.6	0.45	Nil	Nil	Nil	Nil	Nil	P	Nil	+6.2	P	27.1	F6
F7	Light Ale	4.2	0.37	P	Nil	Nil	Nil	Nil	P	Nil	+4.5	P	8.6	F7
F8	20% v/v Lime Cordial	2.55	$<$ 0.01	T	Nil	Nil	Nil	Nil		Nil	+0.4	Nil	2.2	F8
F9	Urine	4.85	2.40	T	Nil	Nil	Nil	Nil	Nil	Nil	+3.1	Nil	30.5	F9
F10	Coca Cola	2.5	0.05	T	Nil	Nil	Nil	P	P	Nil		Nil	7.0	F10
F11	Tap Water	7.7	0.05	0.05	Nil	$<$ 0.1	Nil	$<$ 1 p.p.m.	Nil	Nil	-0.05	Nil	2.4	F11
F12	Silicate Based Cleaning Fluid	9.65	0.01	P	Nil	Nil	Nil	Nil	Nil	Nil	-0.3	Nil	1.2	F12

Key: P - Present
T - Trace