4

ARL-APP-R-84

AR-004-535

AUSTRALIA

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Applied Report 84

RAAF ORION AIRCRAFT A9-300
OXYGEN FIRE(U)

by

S.A. BARTER
L.W. HILLEN

Approved for Public Release

SEPTEMBER 1987

ARL-APP-R-84 AR-004-535

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
AERONAUTICAL RESEARCH LABORATORIES

Applied Report 84

RAAF ORION AIRCRAFT A9-300 OXYGEN FIRE

BY

S.A. BARTER
and
L.W. HILLEN

SUMMARY

This report summarizes the findings of the investigation into the nature and cause of the fire in RAAF Orion aircraft A9-300. This aircraft was destroyed by fire which initiated in the oxygen system as the result of an explosion caused by metal ignition.

DSTO ARL
MELBOURNE

POSTAL ADDRESS: Director, Aeronautical Research Laboratories,
P.O. Box 4331, Melbourne, Victoria, 3001, Australia

CONTENTS

1. INTRODUCTION

Following a ground fire in Orion aircraft A9-300, ARL was requested to examine parts of the Flight Station Oxygen System and (if possible) to establish the mode of ignition of the obvious metal/oxygen fire which had occurred within that system.

This report is based on inspection of the debris from the fire, witness reports on the events prior to and after the fire, inspection of components from other RAAF oxygen systems and a search of the chemical literature for basic research data relevant to this incident.

2. BRIEF DESCRIPTION OF THE EVENTS IN THE FIRE IN ORION AIRCRAFT A9-300

In order to carry out maintenance work on the forward RADAR waveguide of Orion aircraft A9-300 it was nessassary for RAAF personnel to remove the No.2 oxygen cylinder from the Flight Station Oxygen System which is situated under the pilot's seat.

The Flight station Oxygen System is shown in a schematic diagram in Figure 1. Although maintenance manuals required that the system be depressurized to 500psi prior to disconnection of a cylinder, this procedure was not followed in this case. On unscrewing the self-sealing fitting on the outlet of the No. 2 cylinder, the hiss of escaping gas (oxygen) was heard by all personnel in the cockpit. This should normally take only a few seconds as the volume of pipe work, valve blocks, etc. is small (when all valves are working perfectly). After a few minutes, when the hiss had not abated as expected, an attempt was made to close the fitting on the neck of the cylinder. From a later reconstruction of the incident, the RAAF estimated that the rate of oxygen escape was 50 L/min. When resealing was attempted, a violent explosion occurred in the vicinity of the high pressure manifold and check valve assembly. The ensuing fire quickly spread to the rest of the aircraft cabin. A high pressure oxygen manifold and check valve is shown in Figure 2 and the drawing of the component parts in Figure 3.

Several minutes after the start of the fire, oxygen cylinder No. 2 (the oxygen contents of which had been isolated from the rest of the system) exited the aircraft through the port side. This cylinder had overheated and the pressure-relief valve built into the cylinder fitting had then operated. Due to the position of the relief nozzles, a jet of oxygen was directed onto the cylinder itself, adjacent to the neck. Under the prevailing conditions the jet of oxygen, at a temperature high enough to blow the relief valve, formed an 'oxygen lance' which rapidly cut through the cylinder. The remaining oxygen pressure was sufficient to cause the cylinder to be propelled through the side wall of the aircraft.

After the fire, the pressure manifold, which had not been exposed to the full heat of the subsequent cabin fire, was found almost intact (Figure 4), apart from a severely burnt filler manifold (Figures 5,6,&7).

Other damage to the flight station oxygen system included mechanical damage to the pressure-reducing valve and severing of the aluminum tubing which connected the pressure manifold and the check valve assembly to the pressure-reducing valve. The latter defect involved metal failure due to overpressurisation of the tubing (estimated at 5400 psi) as the contained oxygen was heated close to the melting point of the aluminium alloy. As this type of damage was considered to have occurred subsequent to the critical ignition event, no detailed analysis was considered necessary.

3. DEFECTS FOUND IN A9-300

Inspection of the pressure manifold and check valve assembly indicated a number of non-standard conditions.

3.1 Defective Brass Screw

Inspection of the poppet valve from No. 3 inlet poppet chamber (Figure 8), showed that the head of the brass screw (Figure 3, detail A, item 5), which holds the poppet seal (item 7) in place, was missing. A cross-section of the screw was examined (Figure 9a) to determine whether the missing head was due to fire damage or another mechanism. This revealed that dezincification corrosion had occurred. Dezincification is the localized corrosion of brasses which leaves a spongy, structurally weakened mass of the more noble element, copper, partially bonded in place at the site of the corrosion to the corrosion products (in this case mainly zinc oxide). This form of corrosion is promoted by water with a high oxygen content. Some of the remaining copper had oxidized and was concentrated near the surface of the corroded material. The net result of this form of corrosion was that sound metal was slowly changed to a brittle, porous mass of copper. The corrosion extended to the base of the screw (Figure 10) indicating that it had occurred prior to the fire.

The top surface of the screw is shown enlarged in Figure 11. The rough surface is consistent with an advanced state of oxidation/corrosion. The adjacent aluminium poppet valve seal retaining washer (Figure 3, detail A, item 6) had received only superficial damage (Figure 8) during the fire, with no evidence of washer melting (i.e. the temperature was below approximately 650°C). The brass screw has also received only very minor fire damage and the silicone rubber seal was still complete, although distorted by the heat and gas flow. The location of the damage to these various parts suggests that, if the head had been damaged principally by the initial fire, the screw head would have been left concave rather than convex, due to protection afforded by the surrounding material. Concave damage had occurred to the brass screw in the No. 1 poppet from A9-300 and was clearly the result of the fire.

The evidence (of corrosion on the lower part of the screw, and only superficial fire damage to the poppet valve assembly) suggests that the head of the brass screw had corroded away prior to the fire.

The function of the poppet valve screw is to hold the silicone rubber sealing washer in place with the aid of an aluminium alloy washer. Loss of the screw head would not necessarily have prevented the poppet valve from functioning correctly, although it would increase the probability of its incorrect function.

Comparative examination of the brass poppet valve screws (5 in detail A of Figure 3) using metallographic techniques indicated that the corroded screw was manufactured from a leaded, free-machining brass, while screws from other poppet valves in this, and other outlet manifold assemblies examined, did not contain similarly high levels of lead. It appears that the corroded screw was not a standard component of the Flight Station Oxygen System.

3.2 Poppet Valve Seal

Inspection of the poppet valve seat from No.3 chamber showed evidence of score marks on the aluminium alloy face (Figure 12). These score marks were present prior to the fire and would have allowed a slow gas leakage under the silicone rubber washer (Figure 13). In combination with the defective brass screw the score marks ensured that the poppet valve would not function properly, i.e. it would not prevent reverse gas flow in the manifold.

3.3 Evidence for Sonic Flow

Estimates provided by the RAAF indicated that the approximate oxygen leak rate of the oxygen system, when the self-sealing No. 2 cylinder neck fitting was allowed to vent the No. 2 supply line and filler manifold, was 50 L/min. Assuming the following conditions: oxygen flow 50 L/min; temperature 20°C, system pressure 1800 psi, then the effective diameter of the leak was 0.25mm. This value is consistent with the observed deformation of the No. 3 poppet valve washer (Figure 13).

The conditions described are consistent with choked flow through the orifice formed by the defective poppet valve. Flow through the orifice was sonic and possibly supersonic as it expanded into the filler manifold. Any particulate contamination entrained in the gas would have had imparted to it considerable kinetic energy. Sonic flow conditions would have prevailed for any downstream pressure of 900 psi or less given an upstream pressure of 1800 psi. On the attempted reconnection of the No. 2 oxygen cylinder, sonic flow conditions would have prevailed until the downstream pressure reached 900 psi.

3.4 Corrosion Product Contamination

The missing screw head of the No 3 poppet valve, and the corrosion found, strongly suggests that particulate contamination from this source would have been spread throughout the oxygen system. The contaminants could have included brass metal, copper metal, zinc oxide and copper oxide dusts.

These contaminants could have been entrained in the sonic flow discussed in the previous section.

3.5 Charging Fitting Filter

The brass filter within the charging valve assembly (Figure 1) was not adequately designed and was loose within its housing. Inspection of the base of the filter revealed fretting of the base of the sintered brass filter element. This form of wear is the result of small relative movement between solid surfaces in contact under pressure. Apart from failing to trap particles effectively the filter element itself would have contributed to the contamination of the system by being a source of metallic particles.

4. DEFECTS OBSERVED IN OTHER ORION AIRCRAFT

In the course of RAAF investigations, and as a result of ARL observations, components of other Orion aircraft were submitted to ARL for investigation.

4.1 Filters

Filters from a number of Orion aircraft were examined. These were taken from the charging valve assemblies, and all showed signs of fretting, indicating that the element was not sealing properly and had oscillated during charging of the oxygen system. This movement had led to damage of the filter body, removal of material from the filter element and an imperfect seal between the filter body and the filter element. As a result the filters were incapable of effectively removing particles and contributed to metal particle contamination. In addition, the size of the pores of the filters varied between aircraft. Some examples of these filters are shown in Figures 14 & 15.

4.2 Corrosion

A number of pressure manifolds were examined and showed evidence of corrosion (Figure 16). For this corrosion to have taken place moisture must have been present.

In aircraft A9-756, extensive rust deposition was found in the stainless steel tube which connects the pressure manifold to the charging valve. Figure 17 shows the end of the stainless steel pipe where it fits into a union. The extent of the rust deposits is illustrated in Figure 18 where the same tube has been cut midway along its length. The rust in this instance resulted from a poor pickling procedure after fabrication of the part (of local manufacture). This heavy rust deposit led to a fine layer of rust being deposited over the internal walls of the pressure manifold (see Figure 19 and section 4.4).

Another source of rust was the steel cylinders used for ground transport and storage. In the various oxygen systems, there were no filters that were fine enough to remove dusts of this type (particle sizes of 1 micron and less).

It was concluded that rust probably formed a component of particulate contamination in all aircraft and was most probably present in aircraft A9-300 at the time of the fire.

4.3 Manufacturing Techniques

Poor quality control in the manufacture of a pressure manifold is shown in Figure 20. In machining the block to accommodate the stainless steel connectors, aluminium burrs were left protruding from the tops of threads; these burrs were anodised. Such burrs have surface-to-volume ratios which are much higher than that of the pressure manifold block itself. The surface-to-volume ratio is one of the critical parameters controlling metal ignition. While the aluminium burr of Figure 20 has a lower surface-to-volume ratio than other metal particles discussed earlier, these aluminium alloy burrs would provide a means by which particulate ignition could progress to metal block combustion. A comparison could be made with the setting of a wood fire where the progression, match-twig-stick-log, is a familiar sequence. In an oxygen system the sequence would be metal particle, metal burr, screw thread section, metal block.

4.4 An Example of Metal Ignition

As an aid to the investigation of this fire a pressure manifold of aircraft A9-756 was inspected and revealed a non-catastrophic example of metal ignition. The position of the ignition was located just before the central poppet valve on the inlet side of the pressure manifold (Figure 1). The manifold was sectioned to enable detailed photographs to be taken; the two halves of the section are shown in Figures 19&21.

A number of points are of interest. In Figure 21 a molten liquid drop has rolled around the internal passage. Apart from the ignition site, the anodised surface has not been damaged. Figure 19 shows the extension further into the tube, of the roll path of the liquid drop in Figure 21. In addition, liquid has dropped off the ridge above and splattered. Again, the anodised surface has not been damaged. In the central area of the ignition, the anodised coating has been breached and the aluminium block pitted (note where part of one frozen droplet has broken off revealing the undamaged anodised film, Figure 19).

5. ANALYSIS OF THE IGNITION IN A9-756

Analysis of the frozen drops taken from the quenched ignition in A9-756, by the use of Energy Dispersive X-Ray analysis (EDX), showed them to be mainly iron and chromium with some aluminium (most probably the oxides). No nickel was present. This analysis indicates that a metal particle with a high chromium content was involved. The absence of nickel indicates that it was not an austenitic stainless steel as used in the fittings and stainless steel pipework in the Orion Flight Station Oxygen System.

The melting point of an aluminium oxide film (in the case of the high pressure manifold, a film produced by chromic acid anodising) is 2040°C, while the melting point of one of the iron oxides likely to be present (FeO) is 1420°C and chromium oxide (Cr_2O_3) is 2435°C. The latter would 'dissolve' in the lower melting point iron oxide.

The contamination of this manifold with rust was noted earlier (section 4.2). The rust can be seen in Figure 19 as a fine red/brown dust. The danger posed by rust contamination with aluminium components in liquid oxygen and high pressure gaseous oxygen systems is widely recognised [Reference 1], but is not completely understood. On a macro-scale, the reaction of powdered aluminium and ferric oxide ('rust,' which in this context refers to the oxide rather than a hydrated form of the oxide which is commonly referred to by this term) is known as the thermite reaction (equation 1). It is often used as an incendiary device in weapons [Reference. 2].

$$\underset{\text{iron oxide}}{Fe_2O_3} + \underset{\text{aluminium}}{2Al} \longrightarrow \underset{\text{aluminium oxide}}{Al_2O_3} + \underset{\text{iron}}{2Fe} \qquad (1)$$

The reaction is initiated at temperatures of 650-800°C [Reference 4]. Typical methods of ignition include use of a burning magnesium ribbon or a slow burning explosive such as barium nitrate ($BaNO_3$), itself ignited by a primer. The heat of reaction is -849 kJ $mole^{-1}$ of Fe_2O_3 [Reference 3], the negative sign indicating that heat is evolved during the reaction.

The adiabatic reaction temperature (i.e. assuming no heat loss) of the thermite reaction is limited by the boiling point of iron at 2870°C. Due to heat loss by radiation and conduction, the actual temperature will be slightly less but will still be above the melting point of aluminium oxide (2040°C) which forms a molten slag.

The molten iron liberated by the thermite reaction is itself capable of combustion in an oxygen atmosphere [Reference 5].

$$\underset{\text{iron}}{2Fe} + \underset{\text{oxygen}}{(3/2)O_2} \longrightarrow \underset{\text{ferric oxide}}{Fe_2O_3} \qquad (2)$$

The heat of reaction, -825 kJ $mole^{-1}$ of Fe_2O_3, is comparable with the thermite reaction. While the adiabatic combustion temperature is 2877°C, actual temperatures lie closer to 2400°C, recorded for the thermic lance [Reference 5], due to high radiative heat losses. The ignition temperature lies around 1400°C, much lower than the ignition temperature of aluminium (approx. 2000°C). Note that the ignition temperatures of both iron and aluminium are controlled by the melting point of their respective oxides.

If equations (1) and (2) are added together and common terms cancelled then:

$$\underset{\text{aluminium}}{2Al} + \underset{\text{oxygen}}{3/2O_2} \longrightarrow \underset{\text{aluminium oxide}}{Al_2O_3} \qquad (3)$$

In other words, in the ignition of aluminium the thermite reaction can act as an intermediate step. Whereas aluminium is difficult to ignite directly, due to the high ignition temperature of 2000°C, the thermite reaction route provides a lower temperature of initiation (650-800°C).

At the micro-scale the question arises, how is the thermite reaction initiated, given the 650-800°C ignition temperature and the greater scope for reaction quenching due to heat dissipation? Thiessen et al [Reference 4] demonstrated that when iron oxide (Fe_2O_3) particles bombard an aluminium plate at sonic velocities (the plate being kept in a vacuum) then:

(*a*) some of the Fe_2O_3 (non magnetic) is converted to Fe_3O_4 (magnetic) and elemental iron;

(*b*) the surface of the aluminium is pitted;

(*c*) light emission is observed, associated with particle impact.

To accelerate the ferric oxide, a choked nozzle was employed with argon as the carrier gas. Since argon is an inert gas, the chemical reactions that took place were between the aluminium plate and the impacting particles. It was considered that the reactions were due *not to kinetic heating but to* tribomechanically induced reactions.

In a second series of experiments Heinicke and Harenz [Reference 6] showed that metal fires could be initiated by grinding metals and ferric oxide in a ball mill, pressurized with oxygen. The lag between the start of the grinding and initiation of the metal combustion was variable. Fires were obtained with both iron and aluminium. The reaction mechanism is not yet understood in detail. As fires can be initiated by sand plus rust in iron pipework carrying oxygen gas at modest gas velocities ($50ms^{-1}$, Reference 6), it may well be the reactivity of Fe_2O_3 which is the important factor.

In the case of aircraft A9-756, the evidence suggests that a metal particle (chromium or chromium-rich iron) impacted on an anodised aluminium surface coated with rust. The hard Al_2O_3 coating on the aluminium surface may have served as a substitute for sand with the mode of ignition being related to that involved in the ignition of iron pipework by impacting particles of rust and sand rather than to the thermite reaction. i.e. the abrasive action of the aluminium oxide surface had heated the metallic particle to ignition.

This latter mechanism is attractive, since:

(*a*) iron has a lower thermal conductivity than aluminium;

(*b*) metal particles are more easily ignited than block metal (the thermal conductivity of aluminium would have been the factor which quenched the ignition).

If this latter mechanism is the correct one, elimination of metal particles (which tend to be larger) would be more cost-effective than attempting to eliminate totally the finer metal oxide dusts.

No information is available on other metal oxides such as those of copper (CuO, Cu_2O) or zinc (ZnO). On a macro-scale, copper oxide reacts with aluminium even more vigorously than iron oxide, while zinc oxide is unreactive. However, zinc oxide and aluminium will react in a thermite reaction when chlorinated hydrocarbons are present, the combination being the basic formulation for screening-smoke [Reference 2]. The corresponding fluorine compounds would be expected to be effective substitutes for the chlorinated compounds.

Possible modes, or combination of modes, by which the observed ignition in A9-756 was quenched include:

(*a*) depletion of oxygen supply (check valves operating effectively);

(*b*) rapid heat conduction by the aluminium alloy block quenching the temperature of reaction below 2000°C;

(*c*) surperheating of the molten aluminium:- a characteristic of aluminium combustion is the tendency for the metal to boil explosively, lifting the reaction zone away from the metal face and thus quenching the reaction [Reference 7].

The last mode could possibly account for molten material rolling around the internal wall of the filler manifold.

6. FIRE IN A9-300

From eye-witness testimony to the Court of Inquiry it was established that ignition of the fire in aircraft A9-300 occurred within the pressure manifold check valve assembly of the Flight Station Oxygen System. The full details of the damage to the aircraft are to be found in the Court of Inquiry proceedings. This report is limited to damage to the Flight Station Oxygen System.

While the fire started in the pressure manifold check valve assembly, this unit, being located towards the side of the aircraft, was shielded from the later destructive effects of the fire. The part is composed of three manifold blocks bolted together and sealed by silicone rubber 'O' rings, (Figures 2 & 3). The central manifold has three separate chambers leading to the three storage cylinders; the outlet manifold leading to the pressure reducing regulators received only superficial damage. The filler manifold was extensively damaged.

The damage to the filler manifold is shown in Figure 5,6,& 7. In all, approximately 15g of metal was consumed. If all the metal actually burnt (assuming it was pure aluminium, since only a small percentage consisted of alloying elements, then 465kJ of heat would be released.

Part of the metal block is shown in cross-section in Figures 22 & 23. Note the differences between the interior and exterior surfaces of the block. In Figure 22 the cross-section has been etched to reveal the metallurgical structure of the aluminium alloy block. This shows the severely heat-affected areas as being a very narrow band of re-solidified aluminium, indicating that melting of the block occurred immediately in front of the advancing combustion zone. This indicates a *fast-moving combustion* zone (and hence a high rate of heat release) relative to the rate at which heat was being conducted into the metal block. Thus, blow-out[1] of the block did not occur by melting of the block due to heat conducted away from the combustion zone, but as a result of 'torching' (burning away of the aluminium until the combustion zone broke through to the *exterior*).

The maximum time for blow-out of the block, from the sustained ignition, can be estimated by assuming failure due to melting. The heat flux across a segment of

---

[1] Blow-out is defined here as the point when the wall of the metal block is burnt away allowing oxygen and combustion products to enter the aircraft cabin.

From Table 1 and the wall thicknesses at the point of fire, the estimated range for blow-out was between 75-300 milliseconds. The short time span is supported by the superficial damage to the No. 2 poppet valve chamber (Figure 7). Reaction products and surplus oxygen would have been carried through poppet valve chamber No. 2 until blow-out occurred (notice in Figure 7 the rectangular patch where the chamber wall is undamaged, as it was protected by the poppet valve). The greater damage to poppet valve chamber No. 1 indicates that this chamber was pressurised with oxygen (not necessarily full supply pressure) until the collapse of the poppet valve allowed the escaping oxygen to contribute to the combustion of the aluminium block and burn its way through the side wall (Figure 5).

The intensity of the radiant energy being emitted from the fire inside the manifold would have caused the fire to burn towards the No. 3 poppet valve (Figure 7). The limited fire damage to the No. 3 poppet valve (Figures 8 & 13) supports the concept of a short duration fire in the aluminium block.

Other features of the spread of the fire within the block were probably controlled by the distribution of thermal gradients set up within the aluminium. A qualitative description of the control, by thermal gradients, of the direction of combustion in metal blocks has been given by Hirano et al [Reference 9].

6.1 Ignition of Fire in A9-300

The following defects were present in the aircraft's Flight Station Oxygen System:

(*a*) sonic gas velocities due to a faulty poppet valve;

(*b*) corrosion products, including brass dust, zinc oxide, copper and copper oxides, from corrosion of a brass screw due to contact with moisture;

(*c*) probable contamination with metal particles (iron, chromium, brass) and rust as inferred from inspection of other aircraft;

(*d*) possible presence of aluminium burrs left after component manufacture.

While contribution by organic materials and greases to the ignition cannot be eliminated, the observation of ignition due to particle impact on rust in aircraft A9-756 and the high gas velocities known to be present in A9-300 suggests that the thermite reaction is the most probable mode of ignition.

Sustained combustion is dependent on a continuous oxygen supply, ensured in the case of A9-300 by the defective poppet valve. The faulty poppet valve (No. 3) was probably a major contributor to the ignition process besides ensuring the continued supply of oxygen to maintain combustion. Bleeding the oxygen system gas pressure, in A9-300, down to 500 psi prior to the attempted disconnection of the line from the No. 2 oxygen cylinder would not necessarily have prevented ignition of the metal block, as the conditions favourable to ignition could still be achieved (sonic flow, entrainment of stationary or slow moving particles, etc.)

Successful ignition depends on the initial rate of energy release, due to combustion, exceeding the rate of energy dissipation by conduction, radiation and convection. For aluminium with its high thermal conductivity, the ignition sequence to sustained combustion must occur very rapidly, within a hollow block of aluminium alloy, or quenching will occur as in aircraft A9-756 (Figure 19). Thus the estimated blow-out time for the pressure manifold gives an approximate figure for the elapsed time from the initiation of ignition to the fireball observed by the maintenance crew in the aircraft cabin. This strongly implicates the attempted resealing of the No. 2

cylinder fitting (to halt the flow of oxygen leaking through the No. 3 poppet valve) as a factor which assisted the ignition process. Although ignition may have occurred during the conditions that prevailed immediately prior to the attempt at resealing the No. 2 oxygen cylinder, this operation would have disturbed flow patterns, assisting entrainment of stationary or slow moving particles into the high velocity gas stream. It is debatable whether the cylinder should have been left isolated and the rest of the system allowed to bleed off.

The actual site of ignition of the fire cannot be ascertained with confidence. However, given the short duration of the fire before blow-out occurred, the effect of thermal gradients on the direction of fire spread in metal blocks, Reference 9, and the geometry of the block, radial propagation of the fire from the point of ignition could be expected. These considerations and observation of the actual damage observed in the block, lead to the ignition site lying in the connecting passage between the No. 1 and No. 2 poppet valve chambers or the intersection of that passage with the passage leading to the No. 2 poppet valve chamber and facing towards the No. 3 poppet valve (Figure 1 & 6).

7. CONTAMINATION AND DEFECTS IN OXYGEN SYSTEMS

Oxygen systems are used under a variety of conditions. Frequent charging and discharging will lead to the gradual accumulation of contaminants. It would not be physically feasible to keep an oxygen system which is in continuous use entirely free of contamination; any attempts to do so would not be cost-effective. However, as seen in A9-300, the presence of contaminants can have catastrophic consequences. Obviously a balance must be struck in requirements for the cleanliness of oxygen systems.

While it is generally recognised that oxygen systems should be kept clean, maintenance procedures do not reflect a detailed understanding of the contaminants to be avoided [Reference 10].

The suggested ignition in A9-300 involved metal particles and oxide particles ('rust'). Oxide particles tend to be fine dust, while metal particles may be larger. When mobile, larger particles will have greater kinetic energy and are therefore more likely to activate ignition. It is suggested that more effective filters for particles be employed, possibly down to the range of 1-10 microns.

Gross contamination by oxide dusts should be avoided but filtering to eliminate these completely may not be practical. Regular inspection for possible sources of oxide dusts should be mandatory in, for example, steel cylinders used for re-supply. Stainless steel lines should be carefully inspected (and passivated) before installation in aircraft oxygen systems, to avoid rust contamination due to poor pickling procedures etc., during component fabrication.

In oxygen systems, a defect in isolation may not pose a serious hazard. However, when a number of defects of different origin occur in combination, then the risk of fire may be greatly enhanced (the hazard posed by a combination of defects can be far greater than the summation of the individual risks). For instance, propagation of the observed ignition, reported in section 4.4, would have been enhanced if it had occurred adjacent to the metal burr discussed in section 4.3. Had the burr been located within the root of a screw thread then there would have been a greater probability of the metal block igniting. Any other defective condition present which ensures the continued availability of oxygen to propagate the combustion, would further compound the hazard level.

In recognising that it is not practical to eliminate completely oxide dusts and the finer metal particles, great care should be taken to ensure that other sources of system defects and contamination are minimised. Thus replacement parts should be carefully inspected prior to installation to ensure they are not defective and do comply with the manufacturer's and/or RAAF specifications. Where a replacement part differs from the part to be replaced the change should be questioned. Colour changes in 'O' rings provide a good example; these are usually red (silicone elastomer) Black 'O' rings, usually signifying that the elastomer is 'Neoprene', should not be accepted as Neoprene is not satisfactory for use in aerospace oxygen systems [Reference 12]. By strict quality control at all levels, the compounding effect on hazard levels of multiple system defects can be minimised.

8. MAINTENANCE PROCEDURES

The fire in Orion A9-300 brings into question the appropriateness of an 'on-condition' maintenance philosophy. Through the accumulation of contaminants the risk of ignition in an oxygen system could be quite high long before an operational malfunction occurred to warrant maintenance under 'on condition' procedures. It is highly probable that an operational malfunction in conjunction with system contamination would enhance the risk of ignition. Therefore, use of the 'on-condition' maintenance philosophy may lead to a situation where fire is the first indication that maintenance action is warranted. Clearly there is a need for a regular inspection of aircraft oxygen systems for the level of particulate contamination, material degradation and corrosion. The period between inspections must be established by experience, though the frequency of oxygen system recharging should be taken into account. In the case of components made from elastomers (eg. 'O' rings) the environmental temperature regime is also important.

It is concluded that the high pressure oxygen supply system for Orion aircraft, both onboard and off, contained a range of deficiencies. It was only a question of time before a catastrophic event such as the fire in A9-300 occurred.

9. METALS FOR OXYGEN SERVICE

With the exception of gold (and to some extent silver, nickel and copper), metals in common use in high pressure oxygen systems are thermodynamically unstable. The chemical stability of oxygen systems is dependent on kinetic control, ensuring that the rate of chemical reaction is negligible. Any variation which allows chemical reaction via an alternative, lower energy, pathway will destabilize the system. The situation is not dissimilar to that of high explosives and mono-propellants which depend on their thermodynamic instability for their function. Provided high explosives are handled correctly they are 'safe'. However the risk of a malfunction (ie. accidental exposure to shock wave) is finite and often significant. A similar risk situation applies to high pressure gaseous oxygen systems.

The choice of metal for use in high pressure oxygen equipment is a compromise between safety, lightness, strength, corrosion resistance and other factors. No metal is uniquely suited to oxygen service and thus the choice of metal must be based on the particular application [Reference 11].

The fire in A9-300 calls into question the wisdom of using aluminium alloys. However, steel systems can be sensitive to rust and sand contaminants [Reference 6]. Once a fire starts in an aircraft oxygen system it probably matters little whether the combustion temperature is 2400°C (steel) or 3600°C (aluminium). Most of the polymers etc. in the furnishings and fittings of an aircraft can be ignited below 1000°C, in air.

Aluminium is possibly safer than stainless steel, due to the higher ignition temperature (2000°C vs 1400°C; see section 4.4), provided the circumstances under which the ignition temperature of aluminium may be lowered are understood and avoided. Where the risk of contamination is high aluminium should be avoided. The totality of an oxygen system and its usage pattern needs careful consideration when choosing materials. Each system is a separate case. Bar graphs of the relative resistance to ignition (a function of ignition temperature and the square roots of thermal conductivity, density and specific heat), potential fire severity for equal weight (combustion energy/kg), potential fire severity for equal volume (combustion energy/m^3), and the potential fire severity range for equal strength (a function of combustion energy, density and allowable working stress) are given in Figure 24, taken from Reference 11.

Most work on metals in oxygen has involved the effects of variation of temperature and pressure, especially in relation to exposure of fresh metal surfaces due to fracture. The role of *metal particle-metal oxide impact on metal* ignition has only been considered for the case of rust with aluminium. Further research on other metal-metal oxide combinations such as the copper oxides and chromium oxides which could prove hazardous in high pressure oxygen systems is required.

10. CONCLUSIONS

The high pressure oxygen supply system for Orion aircraft, both on board and off, contained a range of deficiencies. It was only a question of time before a catastrophic event such as the fire in A9-300 occurred. The most probable cause of ignition for the fire in A9-300 was a thermite reaction involving aluminium, with or without, either (or both) iron oxide and copper oxide. Energy for the initiation of the reaction probably came from metal particle impact associated with high gas velocities present in the oxygen system at the time (due to a defective poppet valve). That the metal fire started at the time when an attempt was made to close the venting line to the No. 2 Oxygen cylinder may not have been coincidental.

The role of oxides other than ferric oxide (in the form of rust) and other metals in the ignition of aluminium metal in the presence of oxygen is poorly understood. The dearth of information on the ignition of metals in the presence of contaminants draws attention to the need for fundamental research in this area. The goal of such research should be to:

(*a*) provide a rational basis for oxygen system cleaning and maintenance procedures; and

(*b*) improve the safety characteristics of the oxygen equipment.

REFERENCES

1. CLARK, A.F. and HURST, J.G.
   'A Review of the compatibility of Structural Materials with Oxygen'. AIAA Journal 12 (1974) 441.

2. RIEGEL, E.L.
   'Industrial Chemistry' Reinhold, New York (1949) 732.

3. JANAF THERMO CHEMICAL TABLES
   US Clearing House PB 168-370 (1965), PB 168-370-1 (1967).

4. THIESSEN, P.A., ZABEL, E. and SIEGLING, W.
   'Tribomechanically Initiated Iron-Thermite Reactions' Abh. dtsch. Aknd. Wiss. Berlin. K1 Math., Physik, Technik (1967). s.179.

5. HORNE, W. and WILLIAMS, A.
   The Iron-Oxygen Combustion Reaction' J. Inst. of Fuel LI (1977) 126.

6. HEINICKE, G. and HARENZ, H.
   'Tribochemical Effects in Technology III - Ignition of Metal Fires by Tribochemical Reactions'. Die Technick 24 Jg Heft 5 Mai (1969). 313.

7. MALONEY, K.M.
   'Superheating and the Low Pressure Self Extinction in the High Temperature Oxidation of Single Strand Aluminium' J. of Less Common Metals 44 (1976) 155.

8. MALONEY, K.M. and PILLAY, T.C.M.
   The Active Combustion Mechanism of single A1 and Zr Strands in Oxygen as Determined by High Speed Photography' Combustion and Flame 18 (1972) 337.

9. TOSHISUKE HIRANO, KENJI SATO and YOSHIKO SATO
   'Prediction of Metal Fire Spread in High Pressure Oxygen' Combustion Science and Technology 32 (1983) 137.

10. BANKAITIS, H. and SCHUELLER, C.F.
    ASRDI Oxygen Technology Survey, Volume II: Cleaning Requirements, Procedures, and Verification Techniques. NASA SP-3072 (1972).

11. PELOUCH, J.J.
    ASRDI Oxygen Technology Survey, Volume VII: Characteristics of Metals that influence System Safety. NASA SP-3077 (1974) 1.

12 SCHMIDT, H.W. and FORNEY, D.E.
   ASRDI Oxygen Technology Survey, Volume IX: Oxygen Systems
   Engineering Review
   NASA SP-3090 (1975).

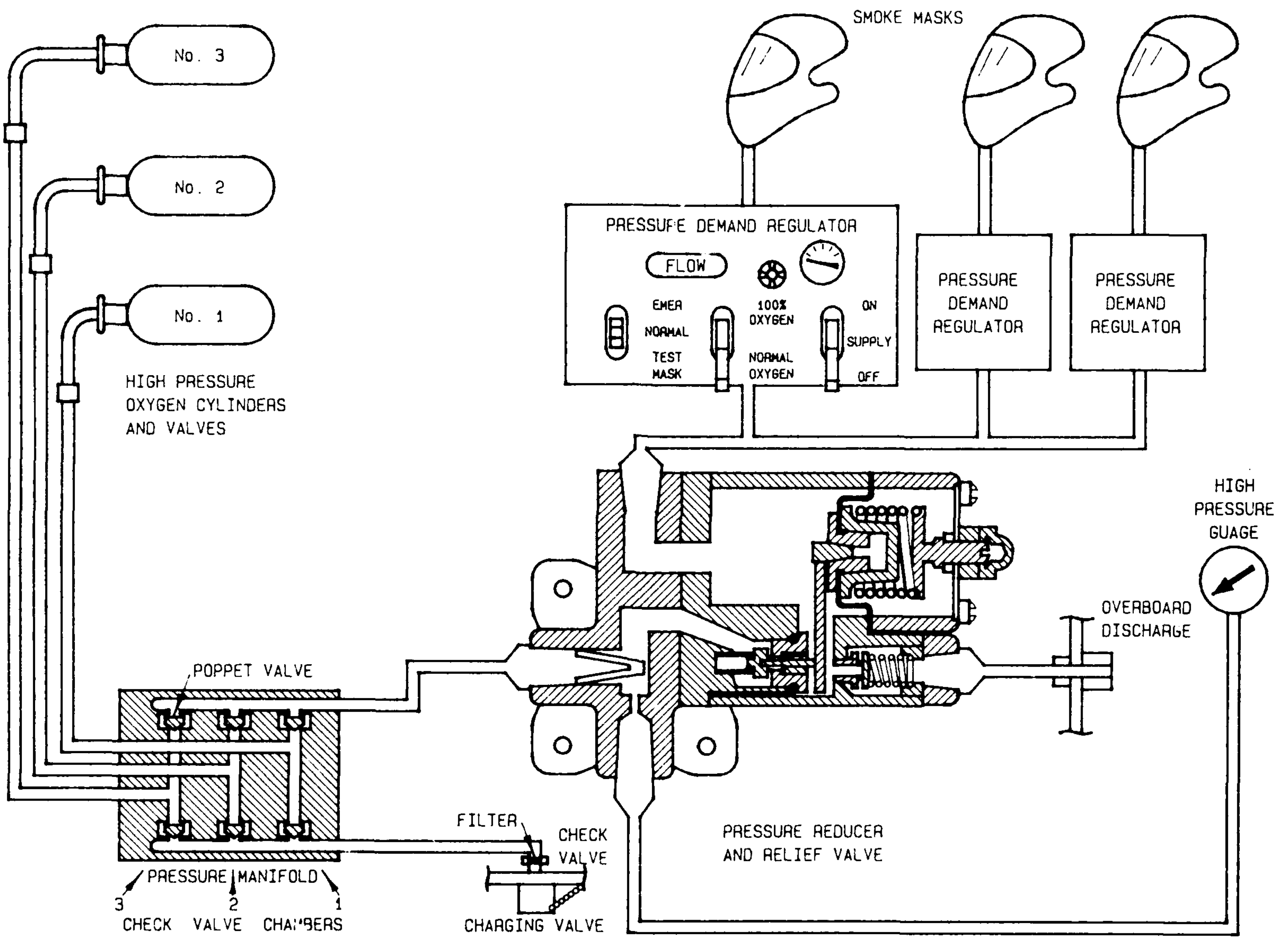


FIGURE 1. OXYGEN SYSTEM SCHEMATIC DIAGRAM.

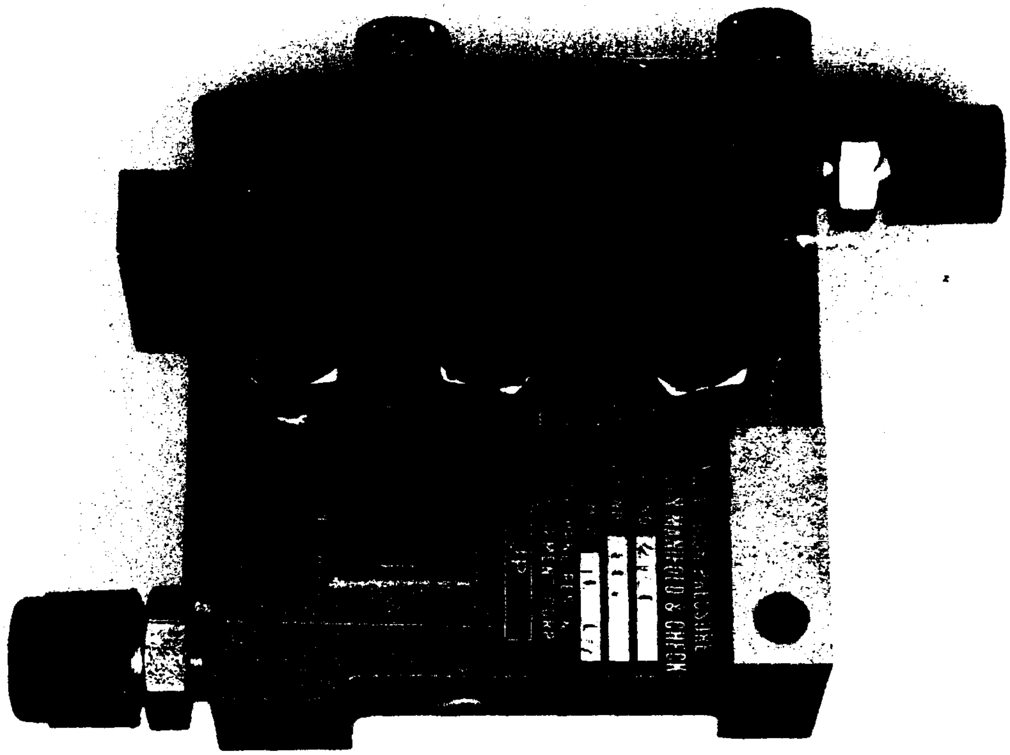
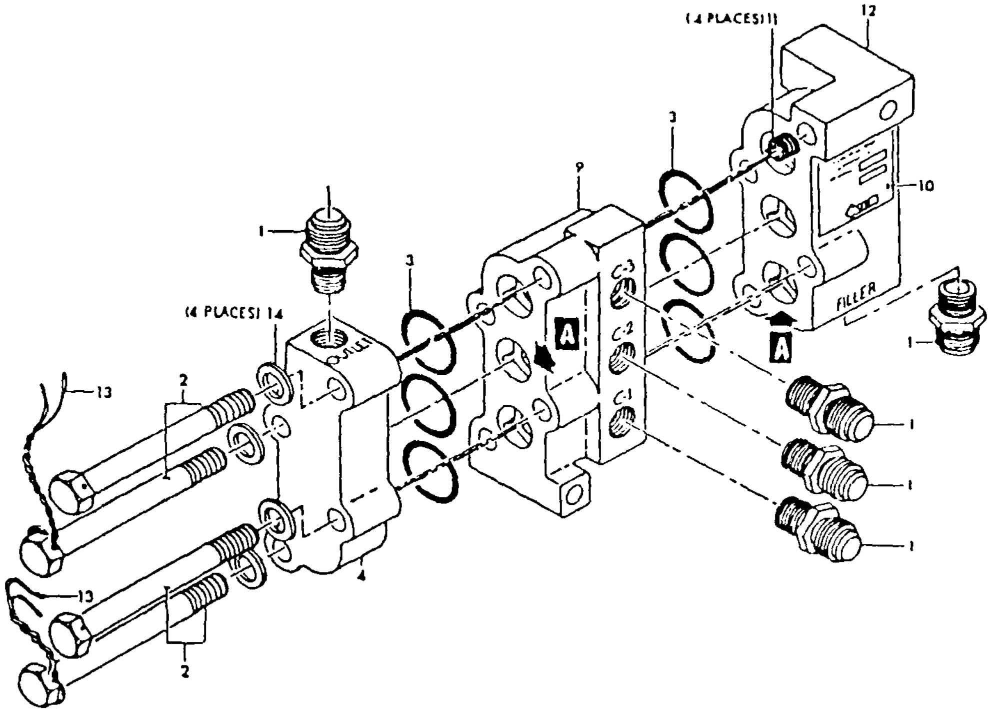
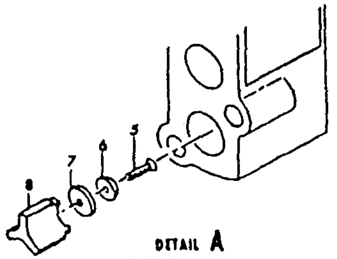


FIGURE 2. HIGH PRESSURE MANIFOLD AND CHECK VALVE ASSEMBLY. THE LARGE ARROW SHOWS HOW THE ASSEMBLY IS POSITIONED IN THE AIRCRAFT.

SCALE: 1 APPROX.





DETAIL A
POPPET ASSEMBLY
(6 PLACES)

1	NIPPLE
2	BOLT
3	PACKING SEAL
4	UPPER BODY
5	SCREW
6	POPPET RETAINER
7	POPPET SEAL
8	POPPET BODY
9	INNER BODY
10	IDENTIFICATION PLATE
11	HELICAL INSERT
12	LOWER BODY
13	LOCKWIRE, MS20995C20
14	WASHER

FIGURE 3. AN EXPLODED VIEW OF THE HIGH PRESSURE OXYGEN MANIFOLD AND CHECK VALVE ASSEMBLY.

NOT TO SCALE

FIGURE 4 HIGH PRESSURE MANIFOLD AND CHECK VALVE ASSEMBLY (ARROWED) AS FOUND 'IN SITU' AFTER THE FIRE IN A9 300

SCALE: 1/10 APPROX.

FIGURE 5. VIEW OF THE BURNT FILLER BLOCK SECTION OF THE HIGH PRESSURE MANIFOLD AND CHECK VALVE ASSEMBLY (AIRCRAFT A9-300). A WHITE SPOT NEAR THE TOP LEFT HAND CORNER (ARROW) MARKS WHERE THE FIRE PENETRATED THE REAR FACE (FRONT FACE OF FIGURE 2)

MAGNIFICATION: 1.5 APPROX.

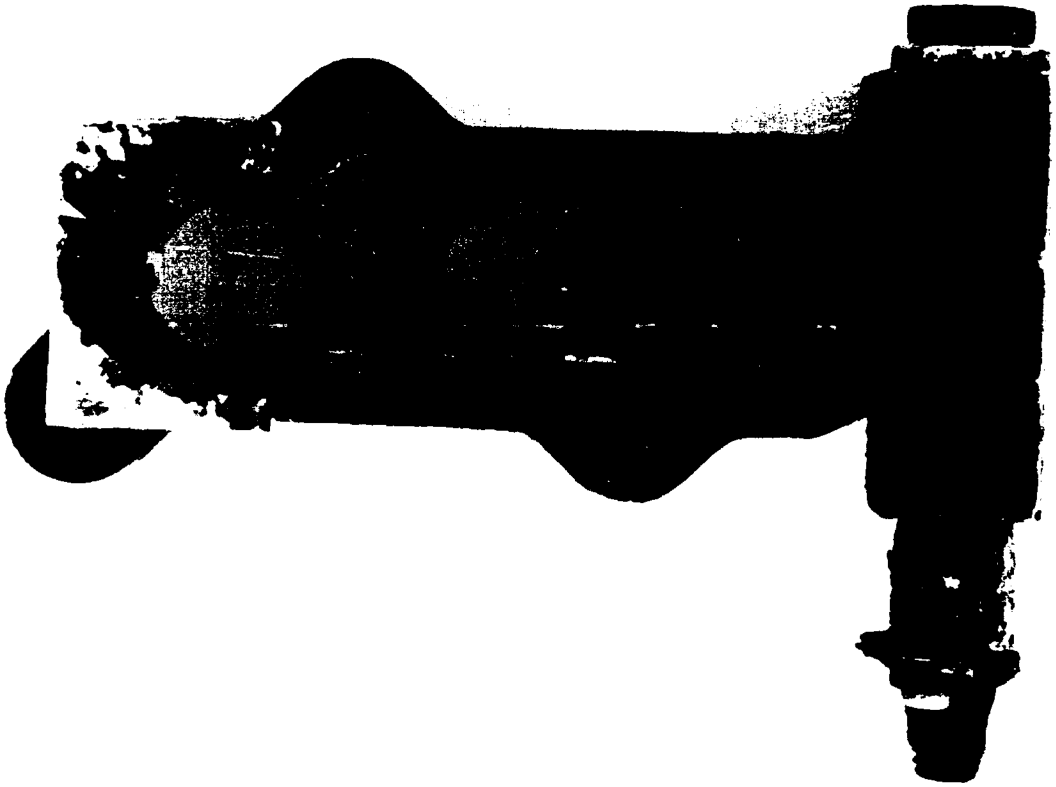


FIGURE 6 VIEW OF THE BURNT FILLER BLOCK SECTION OF THE HIGH PRESSURE MANIFOLD AND CHECK VALVE ASSEMBLY (AIRCRAFT A9-300) FROM UNDERNEATH (SEE FIGURE 2). NOTE THE REMNANT OF THE SCREW THREAD ON THE LEFT (LONG ARROW) INDICATING THAT THE STAINLESS STEEL FITTING FELL OUT TOWARDS THE END OF THE EVENT THE ENLARGEMENT OF THE PASSAGE TO POPPET VALVE CHAMBERS (1) AND (2) IS EVIDENT

MAGNIFICATION 1 5 APPROX

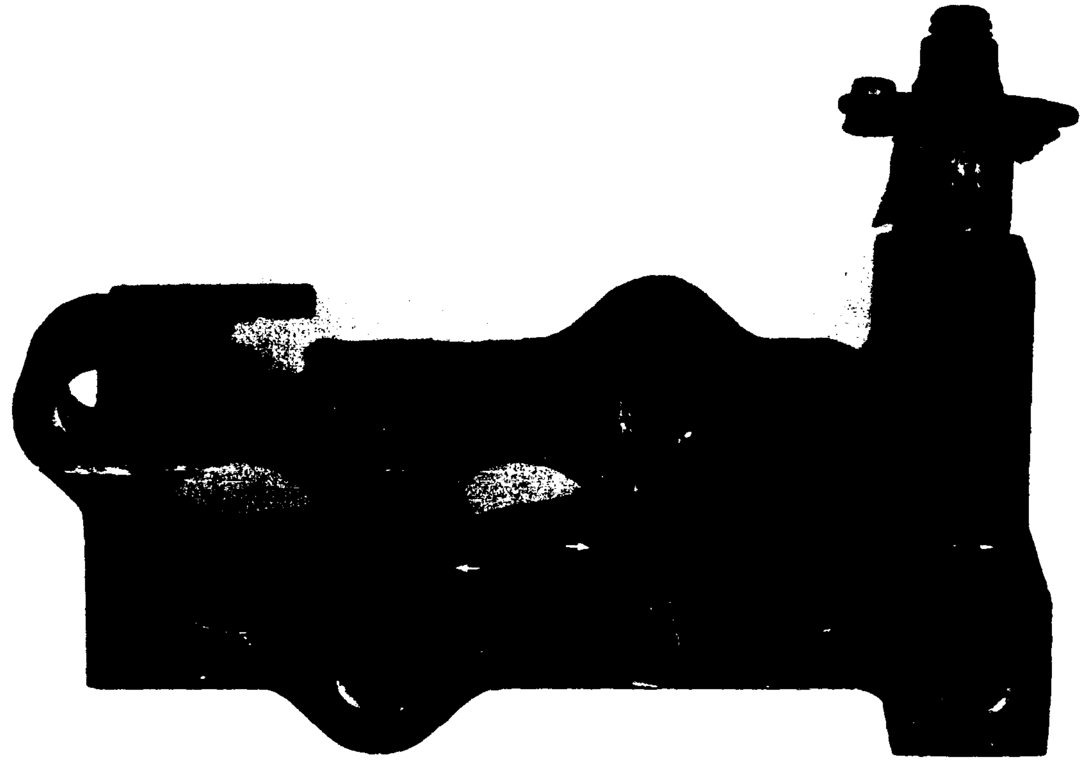


FIGURE 7. VIEW OF THE BURNT FILLER BLOCK SECTION OF THE HIGH PRESSURE MANIFOLD AND CHECK VALVE ASSEMBLY (AIRCRAFT A9-300), FROM THE TOP, LOOKING DOWN INTO THE CHECK VALVE CHAMBERS (No. 1 IS ON THE LEFT). NOTE UNDAMAGED PATCHES ON WALL OF No. 2 CHAMBER (ARROWS) WHERE IT WAS PROTECTED BY THE FLUTES OF THE POPPET (ITEM 8, DETAIL A, FIGURE 3).

MAGNIFICATION: 1.5 APPROX.

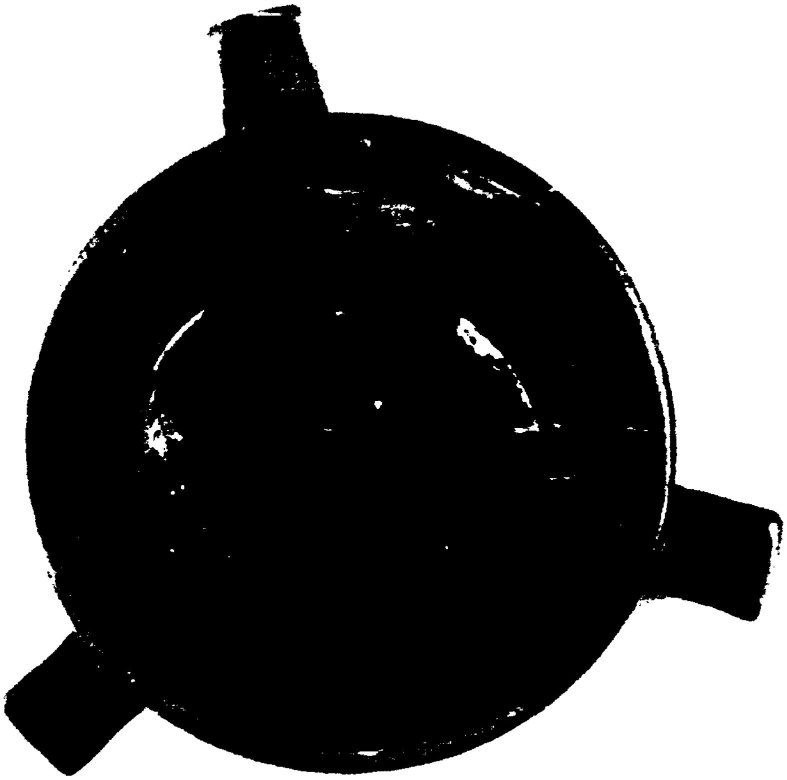


FIGURE 8 POPPET VALVE FROM No 3 INLET CHAMBER NOTE LIMITED FIRE DAMAGE AND ABSENCE OF SCREW HEAD (ITEM 5 DETAIL A FIGURE 3)

MAGNIFICATION 6 APPROX

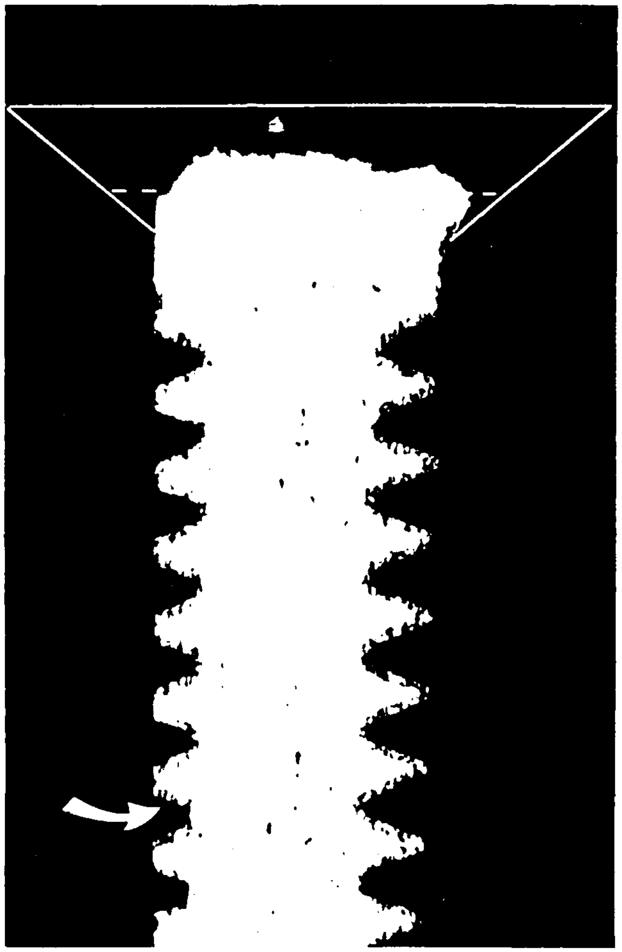


FIGURE 9a. SECTION THROUGH BRASS SCREW OF POPPET VALVE FROM No. 3 CHAMBER (FIGURE 3, DETAIL A, ITEM 5) SHOWING THE EXTENT OF DAMAGE TO THE COUNTERSUNK HEAD (THE ORIGINAL SHAPE IS OUTLINED). AN AREA OF THE CORRODED THREAD (ARROWED) IS SHOWN IN FIGURE 9b

MAGNIFICATION: 40 APPROX.

FIGURE 9b. AN ENLARGEMENT OF THE AREA ARROWED IN FIGURE 9a SHOWING THE EXTENT OF THE DEZINCIFICATION IN THE THREADS. THE GREY AREAS WHICH APPEAR TO PENETRATE THE MATRIX ARE ZINC OXIDE. AN EXAMPLE OF AN AREA OF PRECIPITATED COPPER IS ARROWED.

MAGNIFICATION: 200

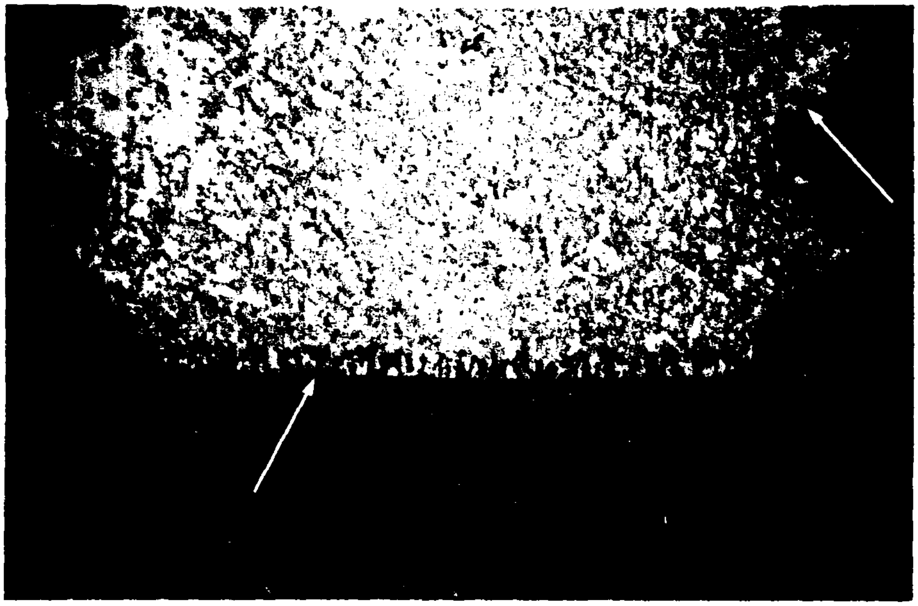


FIGURE 10 SECTION THROUGH BRASS SCREW OF POPPET VALVE FROM No. 3 CHAMBER (FIGURE 3, DETAIL A, ITEM 5). NOTE THE CORROSION (EXAMPLES ARROWED) ALONG THE EDGES OF THE SCREW THREAD AND THE BASE OF THE SCREW AS A RESULT OF DEZINCIFICATION

MAGNIFICATION: 60

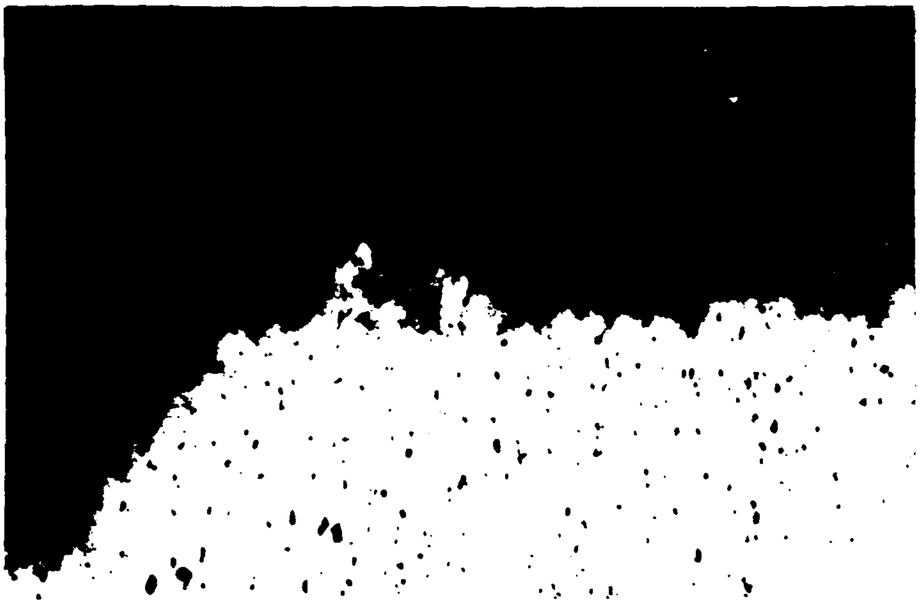


FIGURE 11. SECTION THROUGH THE BRASS HEAD OF POPPET VALVE FROM No. 3 CHAMBER (FIGURE 3, DETAIL A, ITEM 5). THE ROUGH NATURE OF THE SURFACE, WHICH IS COPPER RICH DUE TO SELECTIVE LEACHING, IS CONSISTENT WITH AN ADVANCED STATE OF CORROSION/OXIDATION.

MAGNIFICATION: 200

FIGURE 12. POPPET VALVE FROM No. 3 CHAMBER (FIGURE 3, DETAIL A, ITEM 5) WITH POPPET SEAL, SEAL RETAINER, AND SCREW REMOVED. NOTE LIGHT AREA (LONG ARROW) WHERE POPPET SEAL WAS NOT BONDED TO THE ALUMINIUM BODY AND THE NUMEROUS SCRATCH MARKS. (SHORT THICK SCRATCH ON RHS (CURVED ARROW) IS POST FIRE DAMAGE.)

MAGNIFICATION: 7 APPROX.

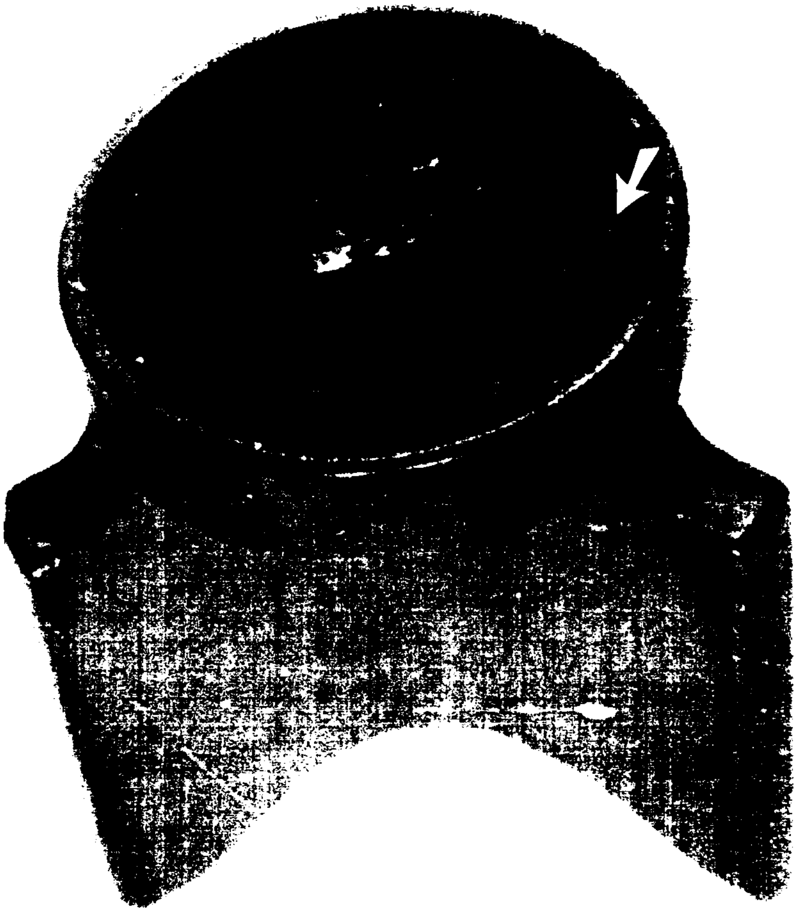


FIGURE 13 POPPET VALVE FROM No. 3 CHAMBER (FIGURE 3, DETAIL A, ITEM 5) SHOWING DEFORMATION AND LIFTING OF THE POPPET VALVE SEAL. SOME OF THE SCRATCH MARKS REFERRED TO IN FIGURE 12 ARE VISIBLE TO THE RIGHT (ARROW).

MAGNIFICATION: 12 APPROX

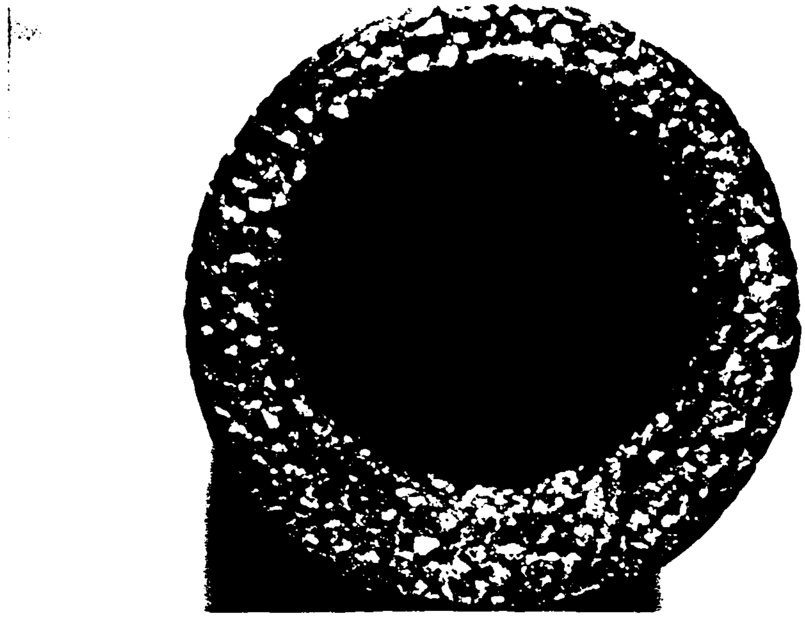


FIGURE 14 A COURSE FILTER FROM AIRCRAFT A9 755 NOTE FRETTING AROUND THE EDGE (ARROWED)

MAGNIFICATION: 9 APPROX

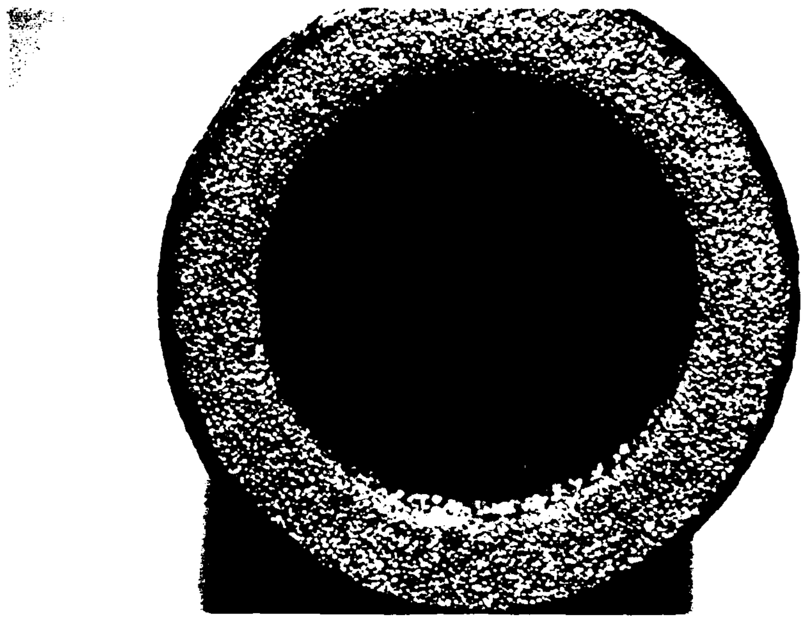


FIGURE 15 A FINE FILTER FROM AIRCRAFT A9 760 NOTE FRETTING AROUND THE EDGE (ARROWED)

MAGNIFICATION: 9 APPROX

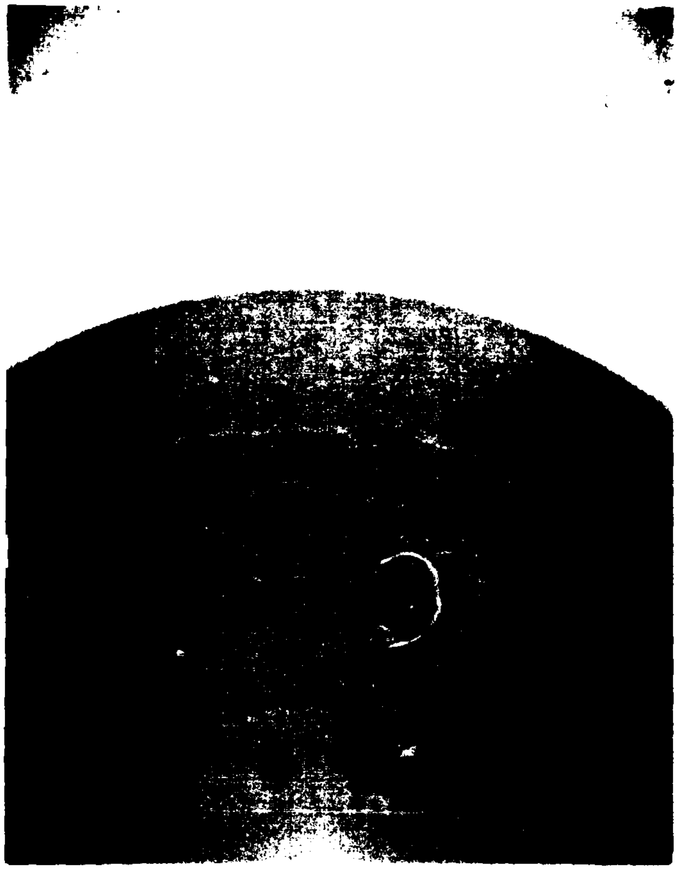


FIGURE 16. CORROSION ON THE WALL OF THE INLET POPPET VALVE CHAMBER OF A HIGH PRESSURE MANIFOLD AND CHECK VALVE ASSEMBLY (NOT FROM AIRCRAFT A9-300).

MAGNIFICATION: 10 APPROX.

FIGURE 17. RUST ON THE INTERNAL WALL OF A STAINLESS STEEL PIPE FROM AIRCRAFT A9-756. THE PIPE CONNECTED THE MANIFOLD CHECK VALVE TO THE CHARGING VALVE (FIGURE 1).

MAGNIFICATION: 10 APPROX.

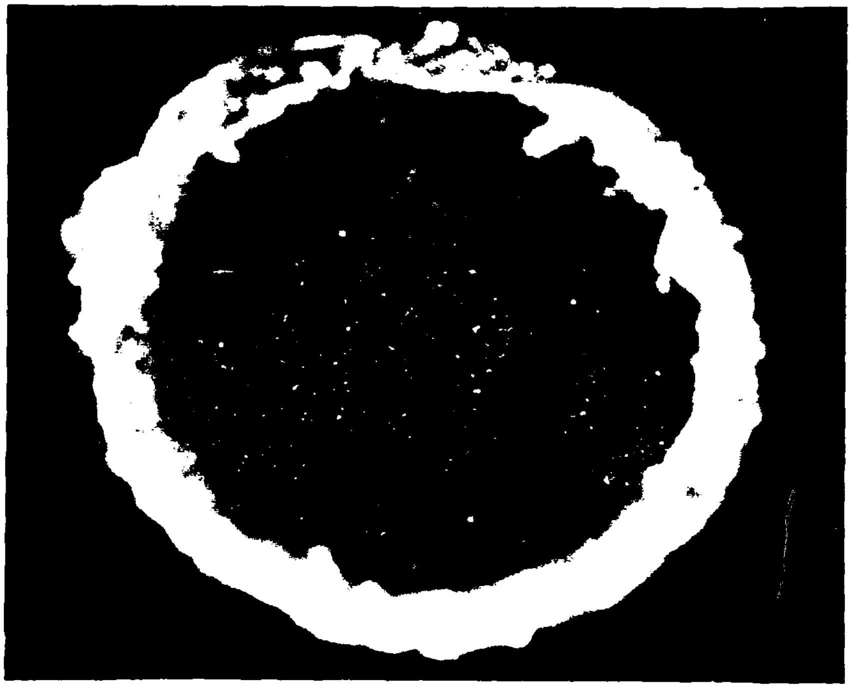


FIGURE 18 A SECTION THROUGH THE CENTRE OF THE STAINLESS STEEL PIPE SHOWN IN FIGURE 17 SHOWING THE EXTENT OF THE RUST DEPOSIT

MAGNIFICATION 10 APPROX

FIGURE 19 AN EXAMPLE OF IGNITION WITHIN THE INLET MANIFOLD OF A HIGH PRESSURE MANIFOLD AND CHECK VALVE ASSEMBLY (TAKEN FROM AIRCRAFT A9-756) NOTE WHERE A BEAD OF FROZEN LIQUID HAS BROKEN OFF (ARROW) TO REVEAL THE UNDAMAGED SURFACE UNDERNEATH. THE BROWN POWDER IS RUST.

MAGNIFICATION: 9 APPROX

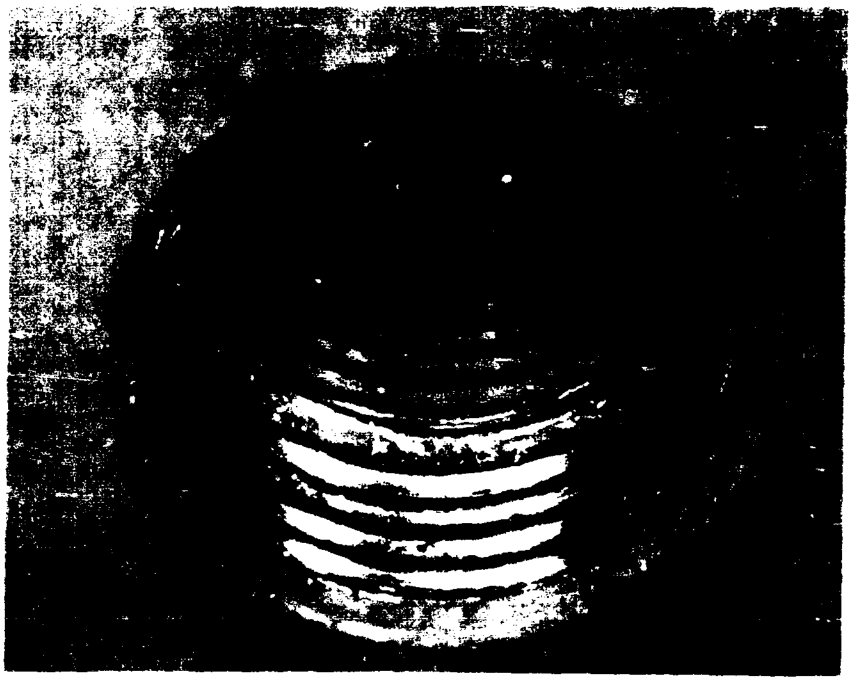


FIGURE 20. THE FILLER BLOCK, OF THE MANIFOLD CHECK VALVE ASSEMBLY, TAKEN FROM AIRCRAFT A9-756 SHOWING A MACHINED SCREW THREAD. THE BRIGHT SURFACE TOWARDS THE TOP OF THE FIGURE IS WHERE A STAINLESS STEEL FITTING HAS BEEN REMOVED TO FACILITATE INSPECTION. NOTICE THE BURR OF ANODISED METAL (ARROW) LEFT ON THE ANODISED SCREW THREAD. METAL BURRS SUCH AS THIS, DUE TO MORE FAVOURABLE SURFACE TO VOLUME RATIO CAN BE IGNITED MORE READILY THAN THE METAL BLOCK. THE LOCATION OF THE METAL BURRS WITHIN A SCREW THREAD (RATHER THAN ON A FLAT SURFACE) WOULD FURTHER ENHANCE THE PROBABILITY OF IGNITING THE MAIN BLOCK OF ALUMINIUM

MAGNIFICATION 8 APPROX

FIGURE 21. THE OTHER HALF OF THE SECTIONED INLET MANIFOLD SHOWN IN FIGURE 19, SHOWING THE PATH (ARROWED) TAKEN BY A BEAD OF MOLTEN MATERIAL. THE PASSAGE AT THE TOP OF THE FIGURE LEADS TO THE No. 2 POPPET VALVE CHAMBER. THE CENTRAL PASSAGE LEADS TO THE 'FILLER NIPPLE' (FIGURE 3).

MAGNIFICATION: 9 APPROX.

FIGURE 22. SECTION THROUGH THE FIRE DAMAGED BLOCK (A9-300) SHOWING THE COMBUSTION ZONE AREA (AREA C). THE HORIZONTAL LINE JUST ABOVE THE FIRE ZONE MARKS THE LIMIT OF RESOLIDIFIED ALUMINIUM ALLOY (ARROW). THE SHALLOW DEPTH OF THIS ZONE EMPHASISES THAT THE RATE OF COMBUSTION EXCEEDED THE RATE OF HEAT TRANSFER INTO THE INTERIOR OF THE BLOCK.

MAGNIFICATION: 570

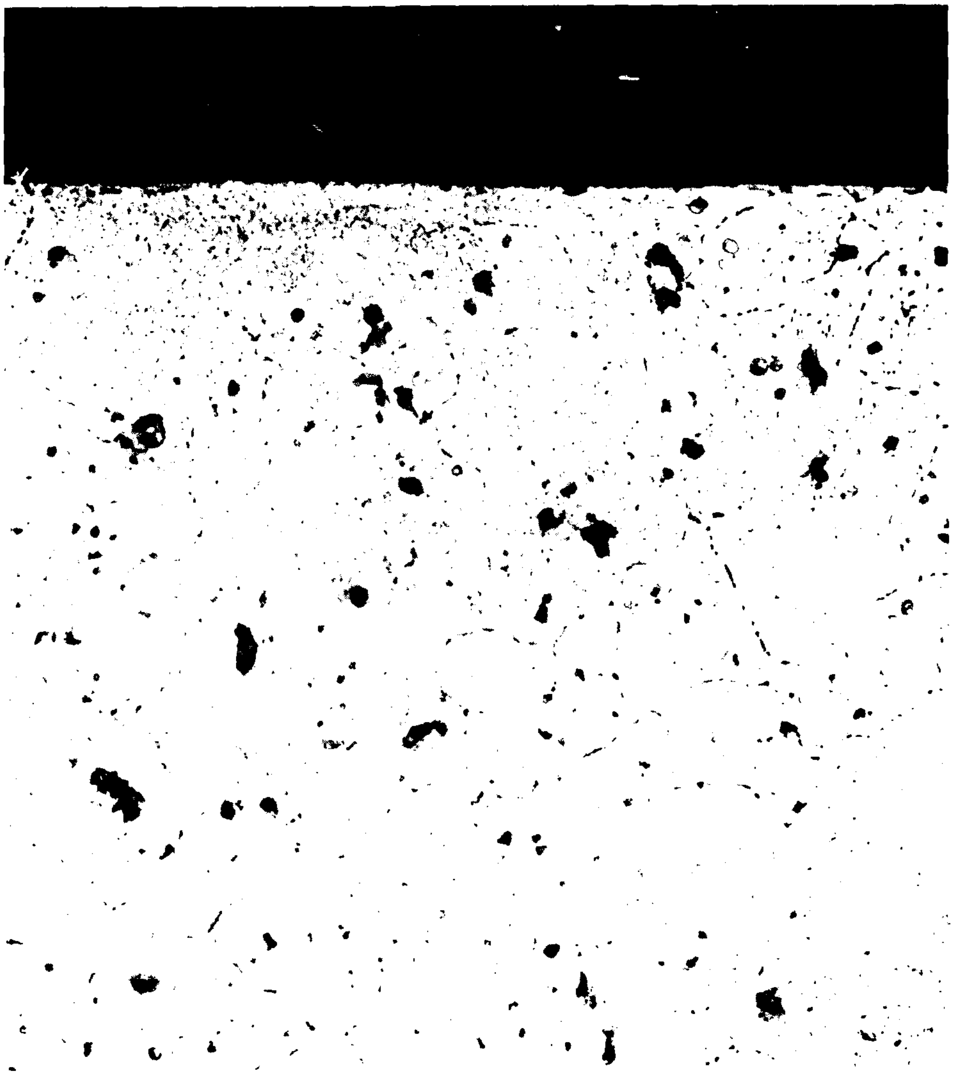
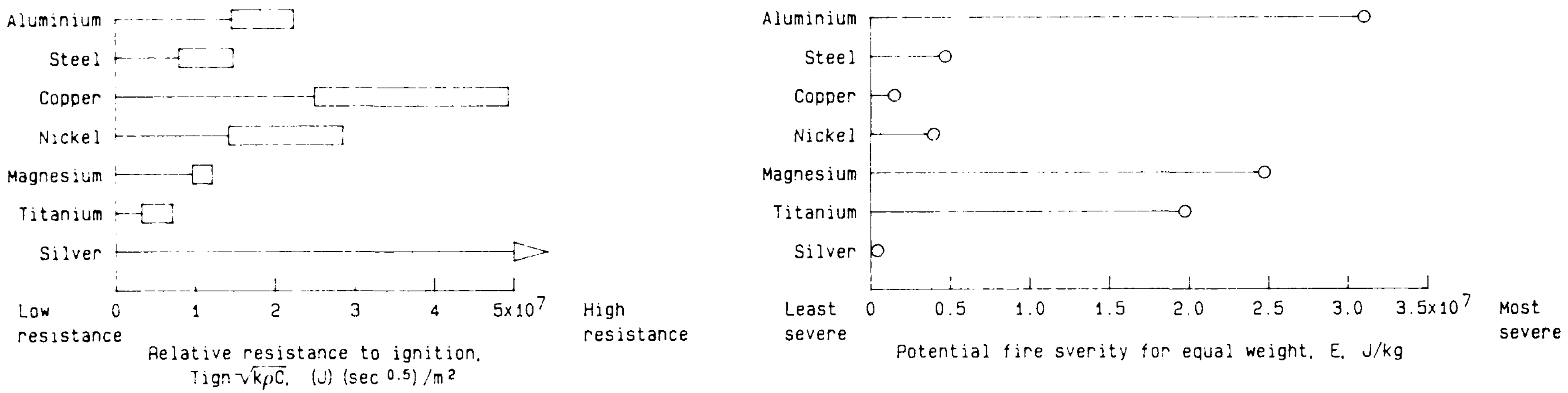


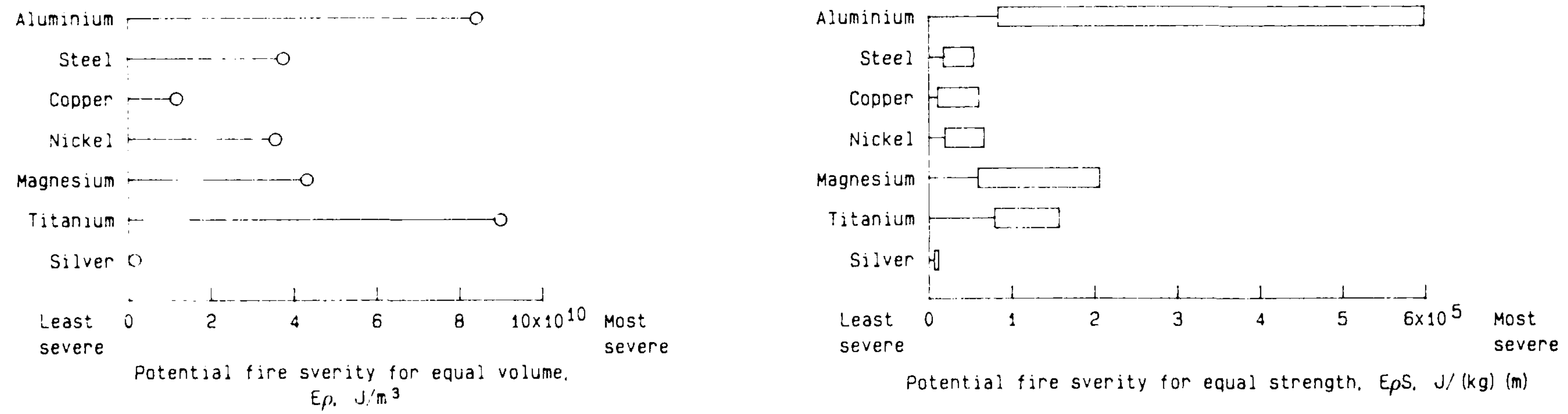
FIGURE 23. SECTION THROUGH THE FIRE-DAMAGED BLOCK (A9-300) SHOWING THE EXTERIOR FACE (TOP OF FIGURE). NOTE THE RELATIVELY UNDAMAGED SURFACE.

MAGNIFICATION: 570



Relative resistance to ignition.

Potential fire severity for equal weight (comparison of components of equal weight but made of different materials).



Potential fire severity for equal volume (comparison of components of equal volume but made of different metals).

Potential fire severity for equal strength (comparison of components of equal strength but made of different materials).

FIGURE 24. GRAPHS SHOWING A SUMMARY OF THE FIRE RISK WITH SEVERAL METAL ALLOY TYPES. COURTESY OF REFERENCE 11 p.42.

DISTRIBUTION

AUSTRALIA

Department of Defence

Defence Central
- Chief Defence Scientist
- Assistant Chief Defence Scientist, Operations (shared copy)
- Assistant Chief Defence Scientist, Policy (shared copy)
- Director, Departmental Publications
- Counsellor, Defence Science (London) (Doc Data Sheet Only)
- Counsellor, Defence Science (Washington) (Doc Data Sheet Only)
- S.A. to Thailand MRD (Doc Data Sheet Only)
- S.A. to the DRC (Kuala Lumpur) (Doc Data Sheet Only)
- OIC TRS, Defence Central Library
- Document Exchange Centre, DISB (18 copies)
- Joint Intelligence Organisation
- Librarian H Block, Victoria Barracks, Melbourne
- Director General - Army Development (NSO) (4 copies)

Aeronautical Research Laboratories
- Director
- Library
- Chief - Aircraft Materials Division
- Head - Aero Propulsion Branch
- Authors: L.W. Hillen
  - S.A. Barter
- G. Clark

Materials Research Laboratories
- Director/Library
- Superintendent - Chemistry

Defence Science and Technology Organisation - Salisbury
- Library

Maritime Systems Division (Sydney)
- Library

Navy Office
- Navy Scientific Adviser (3 copies Doc Data sheet only)
- Aircraft Maintenance and Flight Trials Unit
- Director of Naval Aircraft Engineering
- Superintendent, Aircraft Maintenance and Repair

Army Office
- Scientific Adviser - Army (Doc Data sheet only)

Air Force Office
- Air Force Scientific Adviser
- Aircraft Research and Development Unit
  - Scientific Flight Group
  - Library
- Engineering Division Library
- Director General Aircraft Engineering - Air Force
- Director General Operational Requirements - Air Force
- HQ Operational Command (SMAINTSO)
- HQ Support Command
  - Controller of Logistics
  - Senior Logistics Engineer
  - Staff Officer Aeronautics Equipment Engineering
  - Oxygen Recovery Team (2 copies)
- Institute of Aviation Medicine
- Chief of Air Force Technical Service
- Director General of Air Force Health Services
- Director General Operations
- Director General Tactical Fighter Project
- Director General Aeronautical Equipment Engineering (2 copies)
- Director Maintenance Policy
- Director General Quality Assurance
- CO, No 1 Squadron
- CO, No 3 Squadron
- CO, No 5 Squadron
- CO, No 6 Squadron
- CO, No 9 Squadron
- CO, No 10 Squadron
- CO, No 11 Squadron
- CO, No 12 Squadron
- CO, No 21 (City of Melbourne) Squadron
- CO, No 22 (City of Sydney) Squadron
- CO, No 23 (City of Brisbane) Squadron
- CO, No 24 (City of Adelaide) Squadron
- CO, No 25 (City of Perth) Squadron
- CO, No 26 (City of Newcastle) Squadron
- CO, No 27 (City of Townsville) Squadron
- CO, No 28 (City of Canberra) Squadron
- CO, No 33 Squadron
- CO, No 34 Squadron
- CO, No 35 Squadron
- CO, No 36 Squadron
- CO, No 37 Squadron
- CO, No 38 Squadron
- CO, No 75 Squadron
- CO, No 79 Squadron
- CO, No 292 Squadron
- CO, No 482 Squadron
- CO, No 486 Squadron
- CO, No 492 Squadron

Department of Administrative Services
- Bureau of Meteorology, Library

Department of Transport and Communication
Library
Flight Standards Division

Statutory and State Authorities and Industry
Aero-Space Technologies Australia, Manager/Library (2 copies)
Australian Airlines, Maintenance Development Engineer
Qantas Airways Limited, Aircraft Engineering Manager
Ansett Airlines of Australia, Quality Assurance Manager
Hawker de Havilland Aust Pty Ltd, Bankstown, Library
Hawker de Havilland Aust Pty Ltd, Victoria, Library
Rolls Royce of Australia Pty Ltd, Mr C.G.A. Bailey
Australian Equipment and Oxygen Services, General Manager
Royal Perth Hospital - Medical Library

SPARES (10 copies)
TOTAL (114 copies)

AL 149

DEPARTMENT OF DEFENCE

DOCUMENT CONTROL DATA

PAGE CLASSIFICATION
UNCLASSIFIED

PRIVACY MARKING

1a. AR NUMBER
AR-004-535

1b. ESTABLISHMENT NUMBER
ARL-APP-R-84

2. DOCUMENT DATE
22 SEPTEMBER 1987

3. TASK NUMBER
AIR 87/053

4. TITLE
RAAF ORION AIRCRAFT A9-300
OXYGEN FIRE

5. SECURITY CLASSIFICATION
(PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF.(C) RESTRICTED (R), UNCLASSIFIED (U)).

U	U	U
DOCUMENT	TITLE	ABSTRACT

6. NO. PAGES
47

7. NO. REFS.
12

8. AUTHOR(S)
S.A. BARTER
L.W. HILLEN

9. DOWNGRADING/DELIMITING INSTRUCTIONS
NOT APPLICABLE

10. CORPORATE AUTHOR AND ADDRESS

AERONAUTICAL RESEARCH LABORATORY
P.O. BOX 4331, MELBOURNE VIC 3001

11. OFFICE/POSITION RESPONSIBLE FOR:

SPONSOR AENG-RAAF
SECURITY -
DOWNGRADING -
APPROVAL -

12. SECONDARY DISTRIBUTION (OF THIS DOCUMENT)
Approved for public release.

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH ASDIS, DEFENCE INFORMATION SERVICES BRANCH, DEPARTMENT OF DEFENCE, CAMPBELL PARK, CANBERRA, ACT 2601

13a. THIS DOCUMENT MAY BE ANNOUNCED IN CATALOGUES AND AWARENESS SERVICES AVAILABLE TO....
No limitations.

13b. CITATION FOR OTHER PURPOSES (IE. CASUAL ANNOUNCEMENT) MAY BE ☒ UNRESTRICTED OR ☐ AS FOR 13a.

14. DESCRIPTORS

Aircraft fires
Oxygen supply equipment
Life support systems
Aluminium combustion
Metal ignition

15. DRDA SUBJECT CATEGORIES
0051C

16. ABSTRACT

This report summarizes the findings of the investigation into the nature and cause of the fire in RAAF Orion aircraft A9-300. This aircraft was destroved by fire which initiated in the oxygen system as the result of an explosion caused by metal ignition.

PAGE CLASSIFICATION UNCLASSIFIED
PRIVACY MARKING

THIS PAGE IS TO BE USED TO RECORD INFORMATION WHICH IS REQUIRED BY THE ESTABLISHMENT FOR ITS OWN USE BUT WHICH WILL NOT BE ADDED TO THE DISTIS DATA UNLESS SPECIFICALLY REQUESTED.

16. ABSTRACT (CONT.)		
17. IMPRINT AERONAUTICAL RESEARCH LABORATORY, MELBOURNE		
18. DOCUMENT SERIES AND NUMBER APPLIED REPORT 84	19. COST CODE 43 1220	20. TYPE OF REPORT AND PERIOD COVERED
21. COMPUTER PROGRAMS USED		
22. ESTABLISHMENT FILE REF.(S)		
23. ADDITIONAL INFORMATION (AS REQUIRED)		