A Gold-Chromium-Cobalt Alloy for Sliding Contacts

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A gold base alloy has been developed which can be precipitation hardened to make it suitable for use in sliding contacts. It is hard, strong and wear-resistant and has a low resistivity as well as a low contact resistance. The temperature coefficient of resistance can be varied and can be made low or zero at temperatures in the range 0 to 100°C. Its development is summarised and its properties compared with those of alloys generally used for sliding contacts.

A sliding electrical contact should be of low and constant resistance. It should not tarnish, wear or form insulating films by polymerisation of organic material. Pure gold does not oxidise or catalyse organics, but it wears quickly and then gives erratic values for contact resistance. Gold has low contact resistance compared to that of other precious metals, as can be seen by values given by H. C. Angus (1) and E. M. Wise (2) plotted in Figure 1 for increasing loads. The relation between load and resistance in a contact is complex, a full treatment being given by R. Holm (3). He finds that the slope of the curves plotted as in Figure 1 are similar for most metals so that, from a single point, an estimate of the probable relation with load can be obtained.

A satisfactory gold-based contact alloy needs the increased hardness which can be achieved by alloying without loss of tarnish resistance and with minimum lowering of electrical conductivity. This combination of properties can be obtained by exploiting precipitation hardening in a system in which hardness and strength can result from the dispersion of a fine precipitate, leaving a solute-depleted matrix of virtually pure gold. In these circumstances, the con-

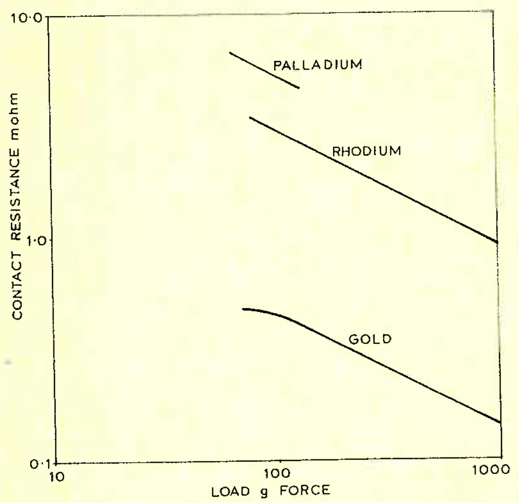
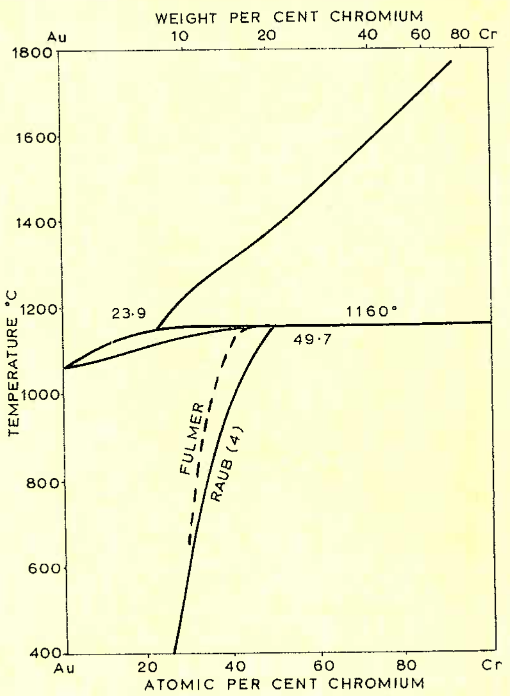


Fig. 1 (above) Resistivity of crossed wire contacts as a function of contact pressure (1, 2)

Fig. 2 (right) The gold-chromium equilibrium diagram after E. Raub



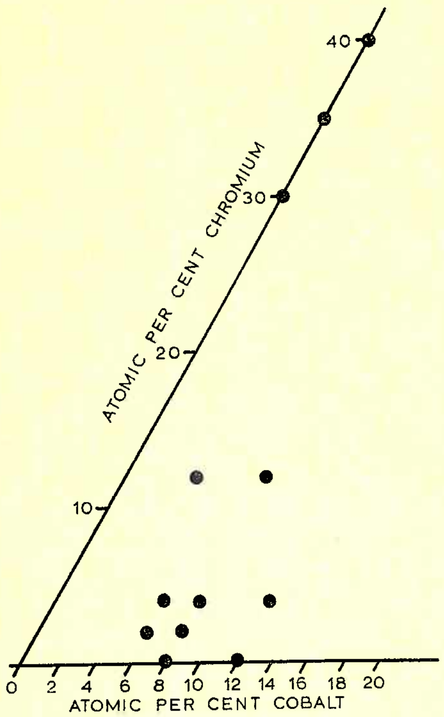


Fig. 3 Compositions investigated in the gold-chromium-cobalt system

ductivity remains high. In the course of a research programme carried out for the Chamber of Mines a suitable alloy of this type has been developed.

Binary Systems

The first system examined for this purpose was gold-chromium. E. Raub's equilibrium diagram (4) for this system is shown in Figure 2. Alloys of 10, 12.5 and 15 weight per cent chromium should all be single phase at 1100°C. However, in alloys made from high purity gold and chromium, the 15 per cent alloy was found still to contain primary chromium which persisted even after 5 hours' heat treatment at 1100°C. The other compositions contained no chromium-rich phase and were therefore in agreement with the Raub diagram. The dotted line on Figure 2 is therefore more probably correct.

The binary alloys responded well to precipitation hardening but even after prolonged ageing at 250 to 350°C were of high electrical resistance, the specific resistance never falling below 100 µohm cm. Attention was therefore given to ternary systems in which the ternary addition could be utilised to reduce the total solute content in solid solution after ageing.

Ternary Systems

Work on the gold-chromium-titanium system was abandoned because titanium had the opposite effect to that intended; hardening was limited and titanium remained in solid solution, thus raising the resistivity. Much better results were obtained from the gold-chromium-cobalt system, from which the compositions shown in Figure 3 were examined.

Tests in which solution treatment and ageing temperatures were varied led to the standardisation of heat treatment as solution treatment at 960°C followed by ageing at 250°C. Later modifications of the alloys enabled a lower solution treatment temperature of 850°C to be used. The variation of hardness with ageing time is shown in Figure 4.

Lowering the chromium-to-cobalt ratio reduced the resistivity after hardening by reducing the residual solute content in the gold matrix. However, chromium cannot be removed completely as the binary gold-cobalt alloy is prone to discontinuous precipitation which causes brittleness. The optimisation of the system requires a balance between the ductility of the chromium alloys and the low resistivity of the cobalt alloys. Resistivities after ageing of the low chromium-cobalt alloys are listed in Table 1.

The alloy with 2 atomic per cent chromium and 8 atomic per cent cobalt has attractive properties, but for these compositions to be useful as sliding contact materials the brittleness caused by the discontinuous precipitation must be prevented. The precipitation structure causing the embrittlement is shown in Figure 5.

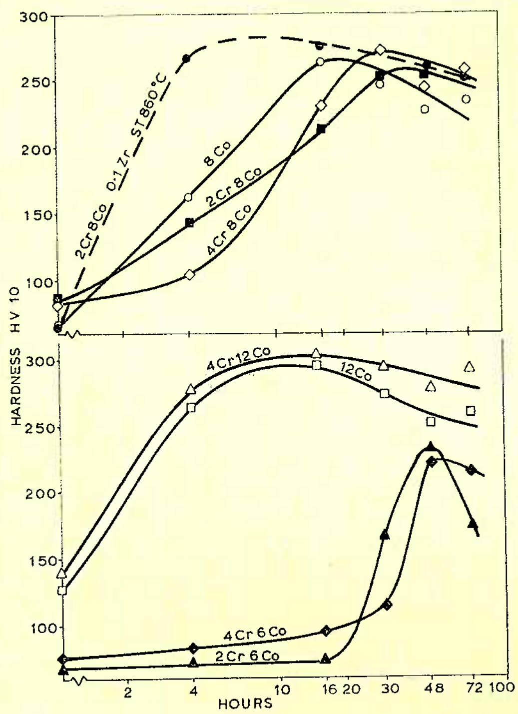


Fig. 4 Ageing curves for ternary Au-Cr-Co alloys (atomic per cent). Solution treated at 960°C and water quenched, aged at 250°C

Table I
Resistivity and Hardness of Au-Cr-Co Alloys in Various Conditions

Composition				Condition					
Cr		Co		Solution Treated 960°CWQ		Solution Treated and Aged 250°C			
						At Peak		Aged 72 Hours	
Atomic per cent	Weight per cent	Atomic per cent	Weight per cent	Resistivity μohm cm	Hardness HV10	Resistivity μohm cm	Hardness HV10	Resistivity μohm cm	Hardness HV10
4	1·14	6	1.93	46.6	75.6	31.0	220	36.7	214
4	1.16	8	2.62	52.2	83	31.2	270	24.1	257
2	0.56	6	1.90	37.2	67.1	23.1	230	30.9	173
2	0.57	8	2.58	44.3	83	18.6	250	14.2	250

Quaternary Alloys

Discontinuous precipitation can, in some cases, be inhibited by trace additions of specific elements. The trace addition should have an atomic size 10 to 15 per cent larger than that of the matrix element, and thus have fairly limited solubility in the matrix. In these circumstances it will preferentially segregate to the grain boundary. The ternary composition of gold-2 atomic per cent chromium-8 atomic per cent cobalt was chosen as a base to which these trace additions were made. The elements investigated were magnesium, indium, lithium, antimony, and zirconium at 0.1 atomic per cent additions. Yttrium and cerium were added at the 0.01 atomic per cent level. All of these additions had the effect of accelerating the onset of precipitation hardening during ageing at 250°C; however, their influence on the control of discontinuous precipitation, varied considerably.

The most successful alloys were those with yttrium which could be hardened to 200HV10 without any appearance of grain boundary migration, and those with zirconium which could be hardened to at least 250 HV10 with boundaries free from discontinuous precipitation.

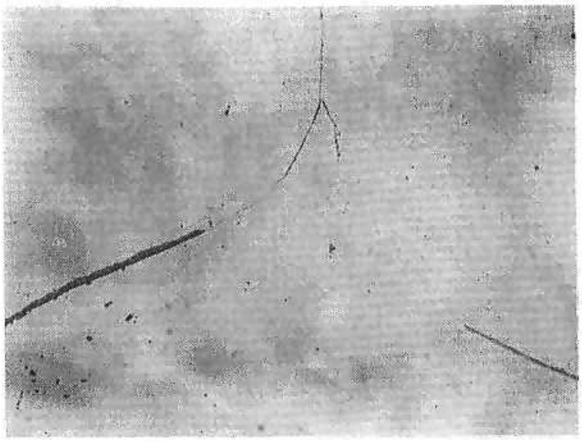


Fig. 5 Discontinuous grain boundary precipitation in a gold-4 atomic per cent chromium-8 atomic per cent cobalt alloy after solution treatment at 960°C, water quenching and ageing for 30 hours at 250°C ×250

After ageing 16 hours at 250°C, the hardness of the zirconium-containing alloy was 276 HV10 and its grain boundaries were free of discontinuous precipitation, while the same composition without trace alloy addition had a hardness of 213 HV10 and showed grain boundary thickening which heralds the onset of discontinuous precipitation. Grain boundary conditions of the alloys with magnesium, yttrium and zirconium trace additions are illustrated by the microstructures in Figure 6. The effect of the zirconium addition on hardening during ageing is shown for the Au-2Cr-8Co alloy, with and without zirconium, in Figure 7. The solution treatment temperature of 960°C was found to give large grain sizes; reducing this to 850°C had little effect on the hardening during ageing but was beneficial in preventing excessive grain growth.

The progress of selection from binary to quaternary systems led to the final choice of the preferred composition alloy, identified as J275, which contains 2 atomic per cent chromium, 8 atomic per cent cobalt and 0.1 atomic per cent zirconium (0.6 weight per cent chromium, 2.6 weight per cent cobalt and 0.05 weight per cent zirconium).

Assessment of the Preferred Alloy

Apart from the hardness values already shown in Figure 7, tensile tests on alloy J275 were made on 0.25 mm diameter wires 10 cm long. The elongations varied from 0.1 to 2.0 per cent, depending on surface finish. The 0.1 per cent proof stress and the ultimate tensile strength for various heat treatment conditions are shown in Table II.

Electrical Resistance

The electrical resistance of the preferred quaternary alloy J275 decreases on ageing to about 22 μohm cm.

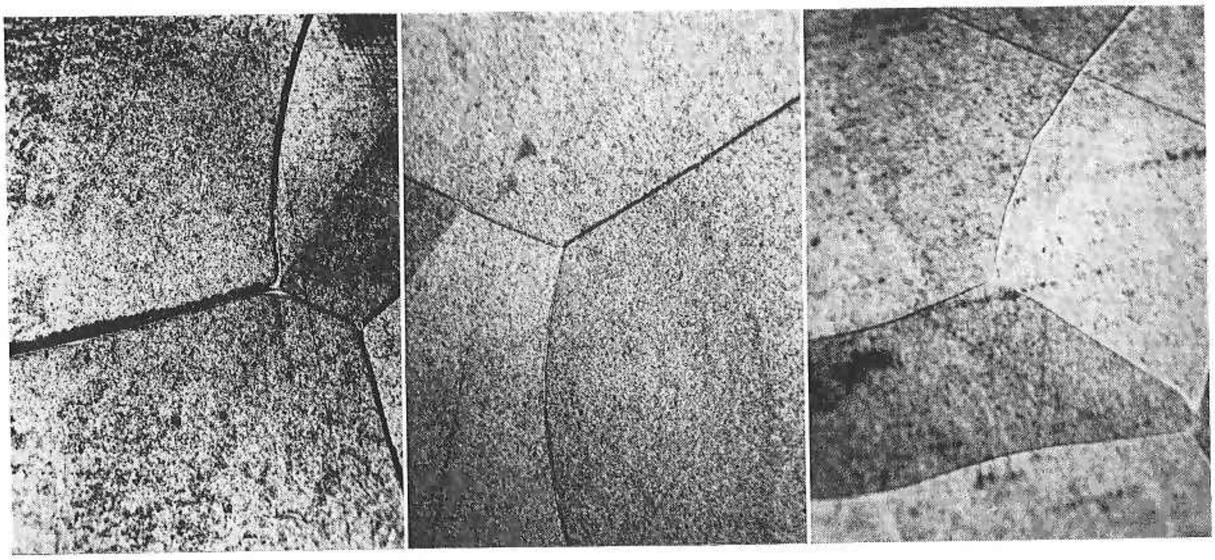


Fig. 6 Grain boundary conditions in a gold-2 atomic per cent chromium-8 atomic per cent cobalt alloy after solution treatment at 960°C, water quenching and 16 hours ageing at 250°C with quaternary trace additions.
Left: 0.1 at.% Mg, severe discontinuous precipitation **Centre: 0.01 at.% Y, slight grain boundary precipitation**
Right: 0.1 at.% Zr, precipitation free boundaries **×250**

In Table III the resistivity of this alloy during precipitation is compared with two standard commercial contact resistance wire materials—Johnson Matthey gold-copper-silver alloy, JMM 625, and the palladium-platinum-gold-silver alloy, JMM 77.

Variation of Resistance with Temperature

The change in resistivity of alloy J275 between room temperature and 100°C has been measured for various heat treatment conditions. The temperature coefficient of resistance is nearly constant over this

Table II

Tensile Tests on 0.25 mm Diameter Wire J275 Alloy after Solution Treatment at 850°C Water Quench and Ageing at 250°C

Ageing Time hours	0.1 per cent Proof Stress		Ultimate Tensile Stress	
	MN/m^2	$tonf/in^2$	MN/m^2	$tonf/in^2$
0	311	20.1	329	21.3
2	349	22.6	407	26.4
4	356	23.1	410	26.5
8	382	24.7	438	28.4
16	527	34.1	569	36.8
24	592	38.3	640	41.4
30	620	40.1	690	44.7

Table III

Electrical Resistance at Room Temperature of Au-Cr-Co-Zr Alloy J275 Compared with Standard Contact Alloys

Alloy	Resistance at Room Temperature in μohm cm				
	Solution Treated 850 °C and Water Quenched	Ageing at 240 °C in hours			
		4	8	10	40
J 275	43.5	39.8	37.2	29.0	22.2
JMM 625	—	14.0★ at 250HV10			
JMM 77	37.5★	33.4★			

★ Temperatures and times not given

Table IV

Contact Resistances for J275 Compared with Standard Alloy Sliding Resistance Materials

Substrate Cupro-Nickel, Rubbing Speed 8cm/s, Load 15g Force, Resistance in mohm. Running Times 40–72 hours

Alloy	J275 Au-Co-Cr-Zr	JMM 77 Pd-Pt-Au-Ag		JMM 625 Au-Cu-Ag
Condition	Solution Treated 850 °C W.Q. Aged 250 °C 30 h. 270HV	Solution Treated 210HV	Solution Treated W.Q. Aged 450 °C 2 h. 320HV	Hardness 250HV10
Maximum contact resistance measured	15	20	21	440
Minimum contact resistance measured	8	10	7	8
Range	7	10	14	432
Number of readings	12	12	5	12
Mean reading	10	14	14	127
Standard mean deviation	2.1	3.1	5	164

range, and depends very critically on heat treatment. The alloy in the solution-treated condition has a negative coefficient; ageing at progressively higher temperatures producing increasingly positive coefficients. Ageing for 2 hours at 250°C after solution treatment produces a material with practically no change in resistance from room temperature to 100°C. This might be a valuable property for some applications. The percentage changes of resistance for a range of heat treatments are plotted in Figure 8.

Sliding Contact Resistance

The apparatus used for measuring the sliding contact resistance was similar to that described by H. C. Angus (1). It consisted of a 56/44 cupro-nickel cylinder rotated at 60 revolutions per minute against which gold wires were pressed at a fixed load. The roller was 1 inch (2.54 cm) diameter giving a wiping speed of 8.0 cm/s. In most of the tests a 15g loading force was used. The springs acted as current connections and very light copper wires were spot welded on near the contacts to act as potential leads. The tests were run for times up to 72 hours, readings being taken at increasing intervals during the run.

The range, average and standard mean deviation of the results for the alloy J275 fully heat treated and for some standard contact wires are shown in Table IV.

These tests showed that as a sliding contact material the new alloy compared well with presently available alloy wires.

Some initial tests were made against a gold-plated roller. At 3 gram force load, generally low (2 to 8mohm) contact resistances were obtained but readings were very erratic. This was due to the pick-up of the soft gold plate on to the harder contact wire. At 15g force the wires rapidly cut through the soft gold plate, and the tests were therefore abandoned.

Solderability

Solderability was assessed by means of the G.E.C. Meniscograph Mk3 solderability tester. This recorded the force acting on a wire dipped into a

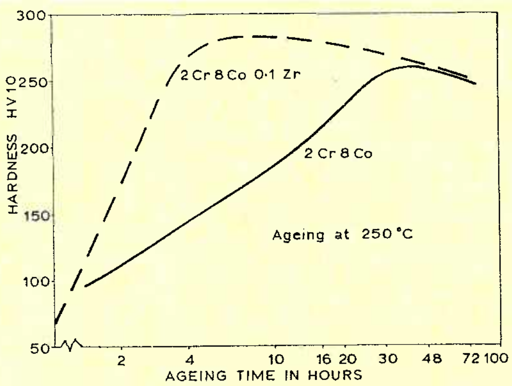


Fig. 7 Age hardening of a gold-2 atomic per cent chromium-8 atomic per cent cobalt alloy with and without 0.1 atomic per cent zirconium. The zirconium free alloy was solution treated at 960 °C and water quenched; the zirconium-containing alloy solution was treated at 850 °C and water quenched

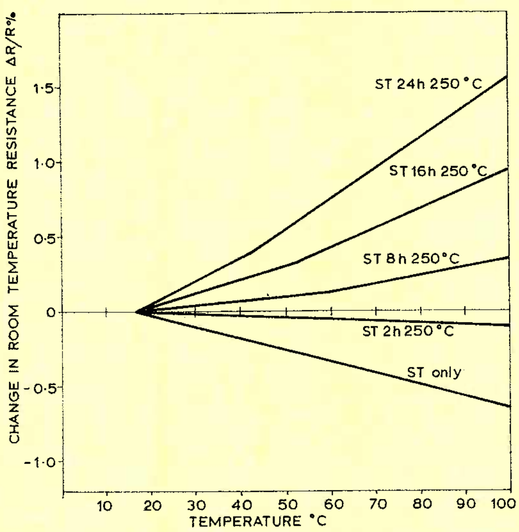


Fig. 8 Change of room temperature resistance up to 100°C for various heat treatments of the gold-chromium-cobalt-zirconium alloy J275

molten bath of 60/40 solder at 235°C in the presence of a non-activated 25 per cent resin flux. Initially an up-thrust on the wire is recorded as the wire depresses the surface of the liquid without wetting, i.e. the meniscus is pushed down; this is shown as a negative reading. As wetting takes place the meniscus gradually comes up to an equilibrium position and during this stage the reading becomes positive and approaches a steady value. A reasonable wetting time is taken as 2 seconds and all the results are therefore given as the force in micronewtons experienced by the wire 2 seconds after immersion. Several dips were made for each wire condition, and the results are averages. Usually the repeats were close together. Variable results are noted. Tests were made for untreated wires, and for the same wires after etching in 50/50 hydrochloric acid/water at 20°C for 15 seconds followed by washing and drying, and for an alkali electrolytic etch with the wire as cathode at 4A/dm^2 for 5 minutes at 20°C. The cathodic etch was followed by an anodic etch at 1A/dm^2 at 20°C. for 1 second, followed by washing.

The solderability results are set out in Table V.

The solution-treated alloy has a solderability comparable with that of pure gold but this decreases on ageing up to 16 hours at 250°C and then becomes slightly better. The electrolytic etch to remove any chromic oxide film formed during heat treatment improved solderability. The solderability revealed by the test is not high but no difficulty was found in practice with making soldered joints, as for instance those that were required in setting up the contact resistance tests. A few solderability tests were made on the zirconium-free alloy; apart from a somewhat greater scatter, they did not differ from those for the quaternary alloy.

Summary of Properties

The most promising alloy developed for sliding contact applications, known as Alloy J275, has therefore the following properties.

It contains 0.6 weight per cent chromium, 2.6 weight per cent cobalt, and 0.05 weight per cent zirconium, balance gold.

Its solution treatment involves heating to 850°C, water quenching and ageing for 30 hours at 250°C. If the solution treatment is carried out in air some surface oxide may need to be removed.

Its resistivity at room temperature when given this

Table V

Solderability as Force in μN 2 Seconds after Dipping into 60/40 Solder at 235°C

Non-activated Resin Flux

Wire	Condition	Force μN (upthrust negative)		
		Untreated	Hydrochloric Etch	Electrolytic Etch
Gold	As drawn	257	195	300
	Annealed	305	285	253
Alloy J 275	Solution treated 850°C W.Q.	228	210	93
	ST+2 h. 250°C	90	125	220★
	ST+8 h. 250°C	−68	50	0
	ST+16 h. 250°C	−170	−65	−70
	ST+24 h. 250°C	−125	−100★	+50

★ Means of rather scattered results

heat treatment is about 24 μohmcm. The change of resistance with temperature depends very much on the heat treatment given. For the above heat treatment the change from room temperature to 100°C will be about 1.5 per cent. For about 2 hours ageing at 250°C the change over this temperature interval is very small.

Tested against a moving cupro-nickel substrate with a contact force of 15 g, the contact resistance was 10 milliohms. This value was reproducible since the standard deviation of 12 results was 2.1 milliohms.

The solderability of the alloy was very dependent upon ageing time. Tests showed the solderability of the fully aged material to be poor compared with pure gold, but in practice soldered joints could be made easily by hand.

For the heat treatment given above the hardness is about 270 Vickers. The 0.1 per cent proof stress for this heat treatment is 620 MN/m^2 (40.1 tonf/in^2) and the ultimate tensile strength is 690 MN/m^2 (44.7 tonf/in^2). Elongation has not been determined. Brittleness results from too high a solution treatment temperature or from excessive grain growth.

Conclusion

A gold alloy has been developed which because of its response to precipitation heat treatment can be made particularly suitable as a sliding contact. It is hard, strong, and wear-resistant, has a low contact resistance and resistivity and at room temperature it is completely tarnish-resistant. The temperature coefficient of resistance is well characterised and in some heat treatment conditions can be made very low or zero for temperature fluctuations around ambient.

References

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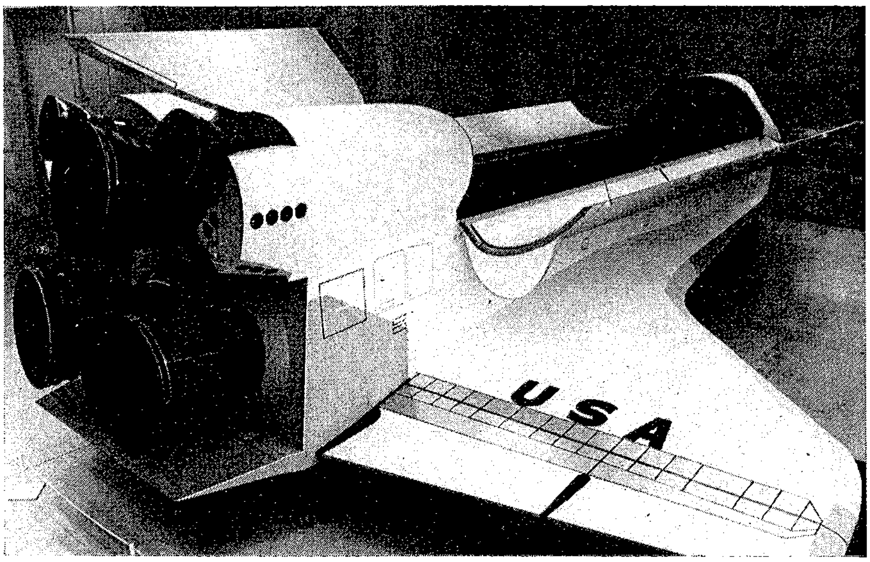
Gold Brazing in the Space Shuttle Engines

The production of the three main engines for the space shuttle is now nearing completion by the Rocketdyne Division of Rockwell International at Canoga Park, California, under a contract from the National Aeronautics and Space Administration.

While a number of joints are electron-beam or tungsten-arc welded, many thousands of assemblies have been furnace brazed in a hydrogen atmosphere with several types of gold brazing alloys to ensure high strength and resistance to corrosion.

Inconel 625 was chosen for a number of components, including the main injection elements, and these were brazed with 70 Au-22 Ni-8 Pd alloy, while the 304 L stainless steel parts of the injector face plate were previously sub-assembled by brazing with 50 Au-25 Ni-25 Pd alloy.

The nozzle assembly is constructed from 1086 tapered and shaped tubes in a high nickel austenitic stainless steel, brazed together as a unit and supported by bands of Inconel 718 with Inconel 903 structural rings. Ageing cycles to develop the full properties of these alloys imposed the need for several stages of brazing at various temperatures, the alloys used ranging from 70 Au-22 Ni-8 Pd to 18 Au-25 Mn-6 Pd-6 Ni-45 Cu. Over 15 pounds of these alloys were used to join more than 10,000 feet of tubing to the Inconel jacket, with a further 2160 brazed joints where the tube ends were attached to the manifold.



A full-scale mock-up of the space shuttle orbiter, a winged, manned vehicle about the size of a DC9 aircraft. Gold alloy brazing has been used extensively in the assembly of the three main engines