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The Flight-Proven AR2-3 Rocket Engine and Future Applications

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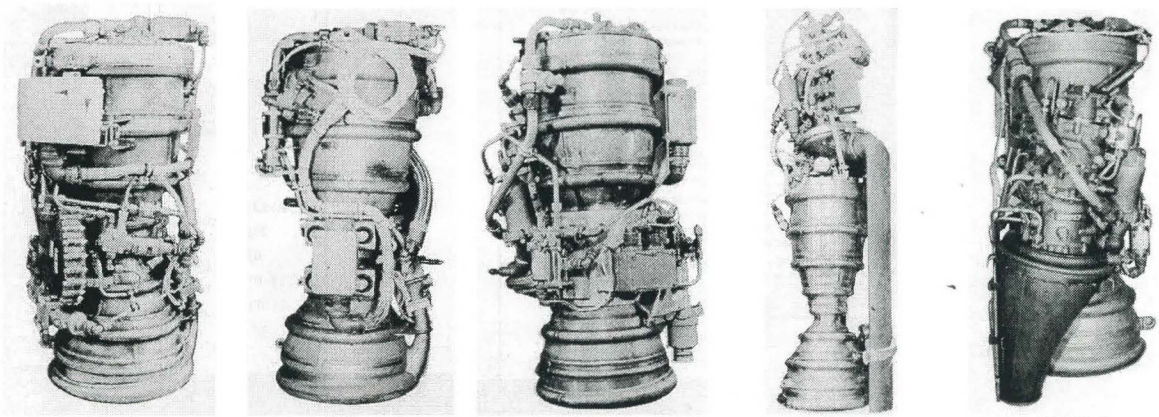
The AR2-3 rocket engine was developed by Rocketdyne in the 1950's, one of a family of aircraft rocket (AR) engines. The first AR engine was the AR-1, which operated at a fixed thrust of 5750 pounds. The engine was flight proven on the FJ-4 aircraft. The AR2 series of engines consist of the AR-2, AR2-1, AR2-2 and the AR2-3. The AR engine series are shown in Figure 1. All of the AR2 series engines provided a mainstage thrust of 6600 pounds and were variable down to 3300 pounds of thrust. The engines use 90% hydrogen peroxide and kerosene. These engines have been used on the FJ-4, F-86 and NF104A aircraft. The AR series rocket engines are integral, compact, liquid propellant, pump-fed engines designed to provide aircraft thrust augmentation.



AR-1 **AR-2** **AR2-1** **AR2-2** **AR2-3**

Figure 1. AR-1, AR-2, AR2-1, AR2-2, AR2-3 Rocket Engines.

AR2-3 Engine Operation

The AR2-3 rocket engine supplies hydrogen peroxide and kerosene propellants to the thrust chamber by oxidizer and fuel centrifugal pumps, directly driven by a single turbine. Pumps and turbine are mounted on the same shaft, eliminating the need for a complex gear train and lubrication system. Oxidizer flows from the pump outlet through the pressure-actuated oxidizer valve, through the thrust chamber cooling jacket, and into the main thrust chamber, through the silver-plated catalytic screen pack, where it is decomposed into super-heated steam and oxygen. Fuel flows from the pump outlet through the chamber-pressure-actuated fuel valve, into the concentric annular-ring type fuel injector, and is injected into the hot, oxygen-rich gases, where it combusts and is exhausted through the 12:1 area ratio nozzle. Auto-ignition of the fuel eliminates the necessity for an ignition system. A small oxidizer flow, of about 3% from the oxidizer pump discharge, is delivered and metered through the thrust control valve into a catalytic gas generator, where it is decomposed into super-heated steam and oxygen to drive the turbine. Throttling control is accomplished by metering the oxidizer flow into the gas generator, thus controlling turbopump output and the chamber pressure. An engine flow schematic is shown in Figure 2. The engine operates on JP-4 or JP-5 propellants indiscriminately. Under

emergency situations, the engine may be operated as a mono-propellant engine using the oxidizer, 90% hydrogen peroxide. The engine operates at a moderate chamber pressure and provided 6600 pounds thrust at vacuum and 246 sec specific impulse. Additional performance parameters are shown in Figure 3.

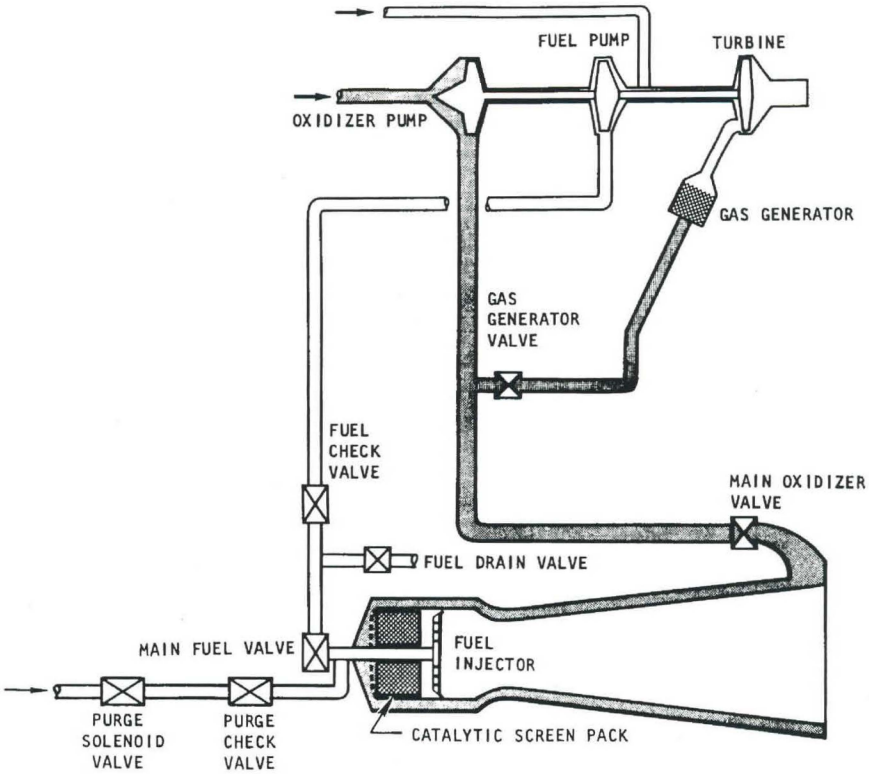
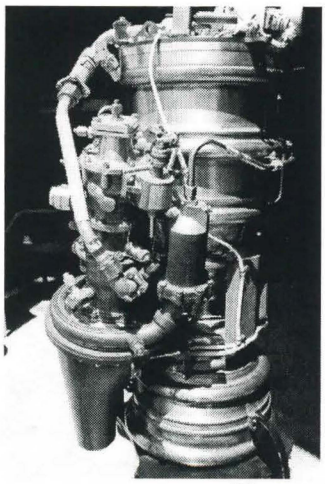


Figure 2. AR2-3 Engine Operating Schematic.



• Propellants	90%H_2O_2/JP
• Thrust, vac (lbf)	6600
• Isp, vac (sec)	246
• Chamber pressure (psia)	560
• Mixture ratio	6.5
• Area ratio	12:1
• Length (in)	32
• Exit diameter (in)	20
• Weight (lbm)	225
• Gimbal angle (degrees)	0
• No. or restarts	multiple
• Engine life	>150 minutes

Figure 3. AR2-3 Engine Performance.

AR2-3 Engine Development

Initial development of the AR series engines began in 1953 with a subscale model of 1000 pounds thrust. A year later, testing was initiated on a 5000 pound thrust engine. Different

decomposition catalyst pack configurations were tried with the 90% hydrogen peroxide. Silver-screen catalysts were made the baseline since they had a longer life than the permanganate stones previously tested with 75% hydrogen peroxide. Three types of fuel injectors were evaluated: a splash-type, a multiple-check-valve type, and a multiple-orifice type. Extensive testing showed that the multiple-orifice injector provided the highest performance and reliability. With such a high mixture ratio, it seems practical to cool the thrust chamber with the hydrogen peroxide. Numerous thrust chamber firings proved the feasibility of this design. Initially the engine system design included a start system that forced peroxide from a tank into the gas generator with pneumatic pressure, where it decomposed and powered the turbine. To reduce weight and improve reliability, the separate start system was deleted. The pneumatic and electrical control systems were initially more complex as a result of following practices used for large rocket engines. These systems were significantly simplified.

During the development testing, preliminary flight rating testing and qualification testing of the AR engine series, over 2200 tests have been conducted totaling more than 45 hours of engine operation. An AR engine has been operated continuously for up to 15 minutes. Up to 4 hours of operation have been accumulated on one engine. In addition to the long duration tests, many start-stop tests were performed to demonstrate the restart capability of the engine. Figure 4 shows an AR2-3 engine being hot fire tested in Rocketdyne's Santa Susana Test Facility.

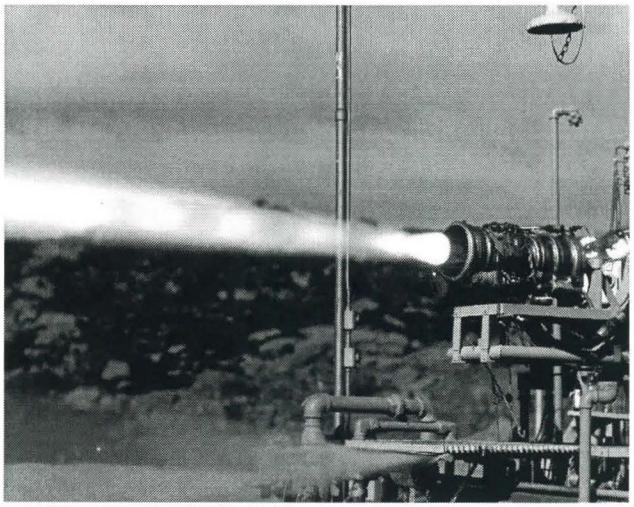


Figure 4. AR2-3 Engine Hot Fire Testing.

AR2-3 Engine Flight History

The FJ-4 aircraft made 103 flights with a total of 3.5 hours of AR2-3 engine operation, based out of the Naval Air Test Center, in Patuxent River, Maryland. The F-86 aircraft made 31 flights with a total of 1.4 hours of AR2-3 engine operation, based out of the Boeing Palmdale facility in California (formerly North American Rockwell). The NF-104A aircraft made 302 flights with a total of 8.6 hours of AR2-3 engine operation, based out of Edwards Air Force Base in California. This aircraft was used as an astronaut trainer, allowing the trainee to experience a few seconds of weightlessness and permitting this aircraft to operate in the fringes of space. This flight history is summarized in Figure 5.

Aircraft	No. of Flights	Hours of Engine Ops	Altitude (ft)	Mach No.	No. of Airstarts
FJ-4	103	3.5	68,150	1.31	6
F-86	31	1.4	71,600	1.22	3
NF-104A	302	8.6	121,000		2

Figure 5. AR Engine Flight Accomplishments.

An NF-104F aircraft is shown in Figure 6, with the AR2-3 rocket engine firing over Edwards Air Force Base.

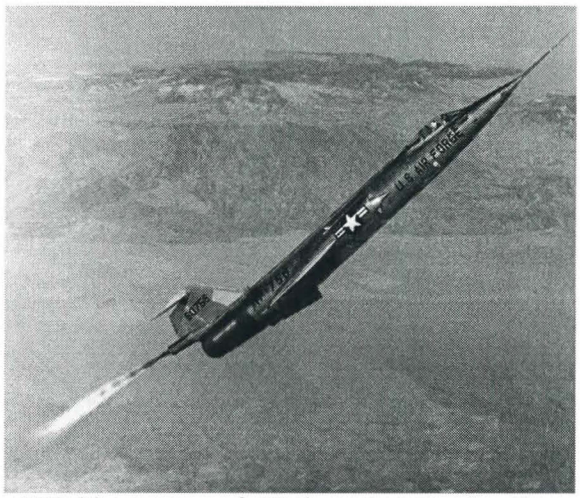


Figure 6. NF-104A Aircraft With AR2-3 Rocket Engine Firing.

AR2-3 Engine Servicing and Overhaul

Servicing and overhaul of the AR rocket engine requires minimal effort throughout its service life due to the simplicity of the engine design. Servicing between flights entails quick turbopump checks and some visual checks of the thrust chamber assembly. These operations can normally be performed in approximately 30 minutes, well within a four-hour aircraft turnaround cycle. After 60 minutes of engine operation, the rocket engine has a minor overhaul to replace worn parts and maintain engine integrity. The turbopump seals and bearings are replaced, the thrust chamber dome seal is replaced and the engine undergoes an electrical/mechanical check and is recalibrated in a hot fire test. After 120 minutes of engine operation, the rocket engine has a major overhaul. Once again the turbopump seals and bearings are replaced and the thrust chamber dome seal is replaced. In addition, all control components are retested, the catalyst screen packs are checked for deterioration and the thrust chamber throat area is checked. The engine electrical and mechanical systems are rechecked and the engine is recalibrated in a hot fire test. The engine has a total service life of at least 50 starts and 150 minutes of operation.

The Air Force concluded that the AR2-3 rocket engine considerably increases the operational envelope of the aircraft. Maximum speed capabilities were increased at all altitudes improving intercept success. Aircraft climb performance and maximum altitude were increased. The reliability of the AR2-3 rocket engine was demonstrated close to 100 percent. Troubleshooting, maintenance, parts consumption, servicing and safety considerations were satisfactory. The

system could be used as an interceptor within the enlarged flight envelope. Pilot techniques required for rocket operation were simple and easily learned. Overall, the AR2-3 rocket engine performed as required and improved the aircraft's performance.

Hydrogen Peroxide Propellant

The AR engines with the hydrogen peroxide and kerosene propellants can handle wide mixture ratio variations which allows smooth, stable starts and restarts and offers very good throttling capability. Hydrogen peroxide is also an excellent monopropellant for auxiliary systems such as gas generators and reaction controls. It is non-toxic and presents a minimum of handling difficulty. It has a long storage life, deteriorating at much less than 1% per year. Hydrogen peroxide features include:

- Non-toxic: simple handling operations, shorter ground operations time
- Storable: long storage life, simple tankage system
- Spillage easily disposed of or neutralized with water
- Non-destructible by ordnance
- Shock resistant
- Non-hypergolic with kerosene.

Storage and handling of peroxide and kerosene are excellent with proper selection of storage tank materials. In the 1950's and 1960's, many manufacturers made 90% hydrogen peroxide, such as DuPont, Shell and FMC. Today, Solvay Interox and DeGussa are producing 90% hydrogen peroxide with plans to provide even higher concentrations in the near future.

Hydrogen peroxide handling was not a major issue during the AR engines program. During the Navy's three year program of the FJ-4 aircraft with the AR rocket engines, approximately 7,000,000 pounds of 90% hydrogen peroxide was handled by Rocketdyne and other contractor personnel and about 300,000 pounds of 90% hydrogen peroxide were handled by the Navy enlisted personnel, efficiently and safely. Fueling procedures were developed to the point where extremely fast turnarounds could be accomplished. Several test flights were completed in one 8-hour day, on a routine basis. An operational servicing truck was used to deliver the 90% hydrogen peroxide to the aircraft. Water was used to pre-wet the area and to wash away any peroxide spillage or overflow. Protective clothing was worn by the servicing crews and no accidents occurred. Those of the aircraft crew who had previously worked on a rocket engine which used nitric acid considered the peroxide much easier and safer to work with.

Future Applications

The AR2-3 rocket engine design was upgraded to higher thrust and performance levels. The AR-3 was designed for 8000 pounds of thrust and the AR-4 was designed for 10,000 – 12,000 pounds of thrust. For the AR-3, most of the control system components could be used 'as is'. Some modifications were required for the turbopump, fuel injector and electrical control box and harness. New components were required for the thrust chamber, main catalyst pack and nozzle extension. The thrust chamber was designed as a tubular wall chamber which was much lighter than the AR2-3's double wall chamber. This chamber operated at a higher chamber pressure and consequently was smaller in diameter requiring a new catalyst pack and smaller diameter fuel

injector. An uncooled nozzle extension provided additional performance. The AR-4 engine used the same thrust chamber, catalyst pack and nozzle extension as the AR-3. The only difference was additional modifications required on the turbopump. The upgraded tubular wall thrust chamber with new catalyst pack was successfully tested at Rocketdyne's Santa Susana Field Laboratory as shown in Figure 7. Today, Rocketdyne is refurbishing existing AR assets for near term applications needing non-toxic, storable propellants, restart capability and reusability, and low risk rocket engines. An AR2-3 rocket engine is planned to be hot fire tested early next year to demonstrate rocket engine operation, 45 years after the AR series engine program start, as a test bed for new hydrogen peroxide related technology.

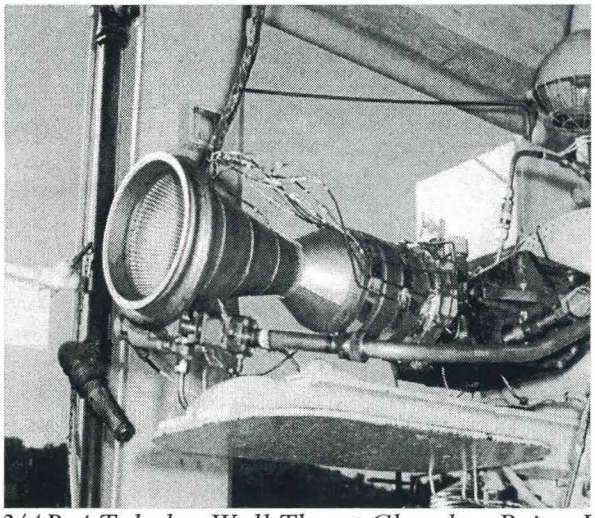


Figure 7. AR-3/AR-4 Tubular Wall Thrust Chamber Being Hot Fire Tested

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