FCR-1656



FINAL REPORT

# LIGHTWEIGHT FUEL CELL POWERPLANT COMPONENTS PROGRAM

BY

R. E. MARTIN

22 February 1980

UNITED TECHNOLOGIES CORPORATION
Power Systems Division

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS8-30637

George C. Marshall Space Flight Center
Huntsville, Alabama 35812
Mr. L. J. George, Project Manager

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## FOREWORD

This final report describes the system definition and component development work completed in defining an alkaline lightweight fuel cell powerplant under NASA contract no. NAS8-30637 from 18 March 1974 through 31 December 1979.

The NASA Project Manager for this contract was Mr. L. J. George. The contributions of Mr. George and other members of the Electrical Power Branch at George C. Marshall Space Flight Center are gratefully acknowledged.

The Project Manager for Power Systems Division was Mr. Ronald E. Martin. Principal Power Systems Division personnel who directed the tasks performed in this program were.

L. M. Handley
A. P. Meyer
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W. F. Bell

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## ABSTRACT

An analytical and experimental development program was conducted on a lightweight hydrogen-oxygen alkaline fuel cell incorporated into the design of a Lightweight Fuel Cell Powerplant (LFCP). The powerplant operates with passive water removal which contributes to a lower system weight and extended operating life.

A preliminary LFCP specification and design table were developed. A lightweight power section for the LFCP design, consisting of repeating two-cell modules was designed.

Two, four-cell modules were delivered to Marshall Space Flight Center. These modules incorporated 0.508 $ft^2$ (471.9$cm^2$) active area Space Shuttle technology fuel cells.

During the program over 1,200 hours of single-cell and over 8,800 hours of two-cell module testing was completed. The 0.25 $ft^2$ (232.3$cm^2$) active area lightweight cell design was shown to be capable of operating on propellant purity reactants out to a current density of 600ASF (645.8 mA/$cm^2$). Endurance testing of the two-cell module configuration exceeded the 2,500-hour LFCP voltage requirements out to 3700-hours.

A two-cell module capable of operating at increased reactant pressure completed 1000 hours of operation at a 30 psia (20.7 N/$cm^2$) reactant pressure.

A lightweight power section consisting of fifteen, two-cell modules connected electrically in series was fabricated. A performance demonstration of the power section is planned under a Lewis Research Center advanced technology fuel cell program.

# I. SUMMARY

This final report documents the activity and results of a long-range analytical and experimental program leading to the definition of an Lightweight Fuel Cell Powerplant (LFCP). The advanced technology lightweight fuel cells of the LFCP design operate with passive water removal which offers significant savings in powerplant weight and extends life. Passive water removal eliminates the requirement for a hydrogen circulating pump and dynamic water separator.

## Objective

The objective of the program was to define the design of a fuel cell powerplant which would meet the requirements of future NASA missions. The design was based upon the advanced technology lightweight fuel cells developed under NASA Lewis Research Center programs.

The design shall be substantiated, and the readiness of the technology for development will be demonstrated by testing of powerplant elements, such as single cells and multi-cell power sections.

## Scope

A lightweight fuel cell powerplant preliminary specification was identified and a lightweight fuel cell powerplant preliminary design table was specified.

Three, two-cell modules, repeating unit of the lightweight power section design were fabricated and tested. In addition, two-single cells and an additional two-cell module of a design capable of increased reactant pressure operation were fabricated and tested.

A lightweight 30-cell power section of the LFCP design was fabricated and a performance demonstration test under a future NASA program is planned.

## Results

Two, four-cell modules incorporating 0.508 $ft^2$ (471.9 $cm^2$) active area Space Shuttle technology fuel cells were constructed, performance checkout tested and delivered to Marshall Space Flight Center for acceleration testing and to investigate low power density operation.

An Lightweight Fuel Cell Powerplant (LFCP) was defined which would be capable of satisfying NASA requirements for advanced space vehicles. A Powerplant Specification and Design Table were established for the LFCP.

A power section for the LFCP design based upon a repeating two-cell module unit was defined.

A total of 8,855 hours of two-cell module testing and 1,222 hours of single-cell testing was completed. Endurance testing of the two-cell module configuration exceeded the 2500 hour design voltage requirement of the LFCP design.

A two-cell module configuration demonstrated that the effect of propellent purity gases on cell performance was very small. The evaluation was conducted at current densities to 600 ASF (645.8 mA/cm$^2$) with hydrogen and oxygen being diluted with up to 0.5 percent Helium to simulate gases that might be obtained from space vehicle propellent tanks.

A two-cell module incorporating a passive water removal assembly capable of operating at increased reactant pressure, completed over 1000 hours of operation at a 30 psia (20.7 N/cm$^2$) reactant pressure.

A 30-cell lightweight power section consisting of fifteen, two-cell modules was constructed. A performance demonstration test of the power section is planned under a Lewis Research Center advanced technology fuel cell program.

Conclusions

- Performance and endurance testing of the two-cell modules has shown that the design will:
  - -- Satsify the 2500 hour voltage requirements of the Lightweight Fuel Cell Powerplant Design.
  - -- Operate with propellent purity reactants with no significant impact upon cell performance.
- Additional endurance testing of two-cell modules incorporating passive water removal assemblies capable of increased reactant pressure operation will be required to demonstrate long-term performance stability.
- A performance demonstration test of the 30-cell lightweight power section designed and constructed during this contract period of performance will be necessary to verify cell reactant distribution, product water removal operation, thermal characteristics, performance with time and structural integrity.

# II. INTRODUCTION

## Background

Power Systems Division (PSD) of United Technologies Corporation has developed several hydrogen-oxygen alkaline fuel cell powerplants for space and undersea applications. PSD has built upon the experience and the lessons of the Apollo program by continuously upgrading and expanding the capabilities of the alkaline fuel cell powerplants through parallel development of basic technology and powerplant hardware. The powerplants which PSD has developed and the improvements in technology they have incorporated are shown in Figure 1.

The Apollo PC3A-2 powerplant, the first in a series, was a complete powerplant successfully qualified for manned space flight. Ninety Apollo fuel cell powerplants were delivered, successfully completing sixteen flights including nine lunar, three skylab and a Apollo-Soyuz mission. A total of 10,750 hours of flight time was completed without incident.

The PC8B series of powerplants was developed under in-house sponsored programs to improve performance, startup characteristics, operating characteristics, endurance, and reduce powerplant weight beyond the achievements of Apollo. The PC8B-1 was the first powerplant incorporating low-temperature, matrix-type alkaline cells configured for space applications. Cell active area of 0.4 $ft^2$ (371.6 $cm^2$) was the same as Apollo. For compatibility with the Apollo Service Module, the PC8B-1 retained the Apollo ancillaries and mounting structure. The PC8B-2 was identical to PC8B-1 except that the interface panel and mounting structure were modified for compatibility with the Air Force Manned Orbiting Laboratory (MOL) vehicle.

In 1969, the PC8B was repackaged with a stack of 0.5 $ft^2$ (464.5 $cm^2$) active area cells. Designated the PC8B-3, this powerplant was operated as a demonstration unit for more than a year, accumulating 97 starts and more than 6000 hours on reactants. The cooling system was improved, its rating was raised from 2.5 to 4.5kW and it was designated the PC8B-4.

The 5kW PC8C was built in 1971 with a stack of 0.5 $ft^2$ (464.5 $cm^2$) active area cells of the high power density type. This cell was developed in the late 1960's in Air Force and in-house IR&D programs. Originally developed for operation at high current densities, typically 3000 ASF (3229 $mA/cm^2$), the cell was found to have superior endurance as well. Endurance testing of this cell configuration in a NASA-LeRC program demonstrated over 11,000 hours of operation and a subscale laboratory cell in a PSD IR&D program exceeded 35,000 hours of testing. This cell configuration has been used in all subsequent low-temperature alkaline fuel cell powerplants. The PC8C was used as a demonstrator powerplant for almost two years. During this period it accumulated 100 self-energized starts.

The Navy 20kW PC15B, the NASA 5kW DM-2, the PSD 15kW demonstrator X-712, and the Space Shuttle PC17B all incorporate low-temperature, alkaline electrolyte fuel cells of the high power density type, a pumped liquid thermal control subsystem, a circulating hydrogen water removal subsystem and a reactant control subsystem with coupled regulators.

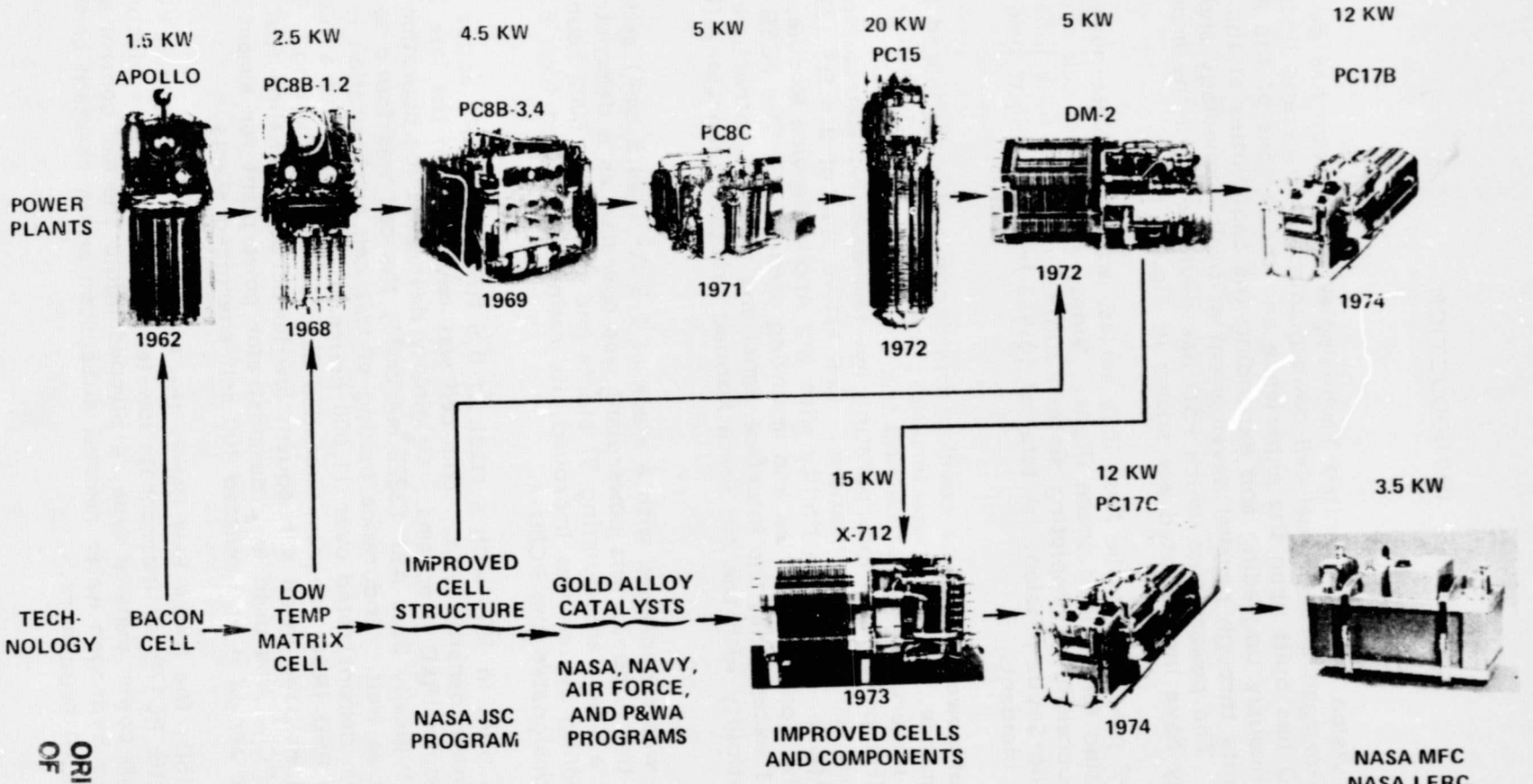


Figure 1. Powerplant Development History

The largest powerplant in the series is the 20kW PC15 hydrogen-oxygen powerplant developed under the Navy sponsored Deep Submergence Rescue Vehicle (DSRV) program. It was designed to supply propulsion and hotel power for deep-diving manned submersibles. Three, 20kW, 128 cell powerplants were built and tested for 877 hours during the program. A total of 137 hours of field operation has been completed.

The DM-2 was developed for NASA-JSC to demonstrate Space Shuttle fuel cell technology, Its continuous output rating was 5kW and has a 7.5kW short duration overload capability, limited by its coolant pump and condenser capacity. The DM-2 power section consisted of 34, 0.5 $ft^2$ (464.5 $cm^2$) active area cells. The powerplant operated over a simulated Space Shuttle power profile for 5072 hours, Figure 2, the equivalent of 31 missions. The powerplant demonstrated 21 self-energized ten minute starts. Two six-cell power sections tested under this program accumulated 10,000 and 10,500 hours of operation, Figure 3, and a hydrogen circulation pump was tested for 10,000 hours.

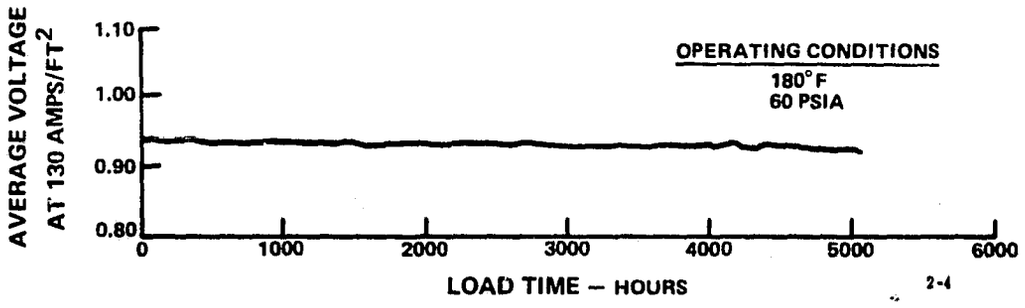


Figure 2. DM-2 5000 Hour Test Summary

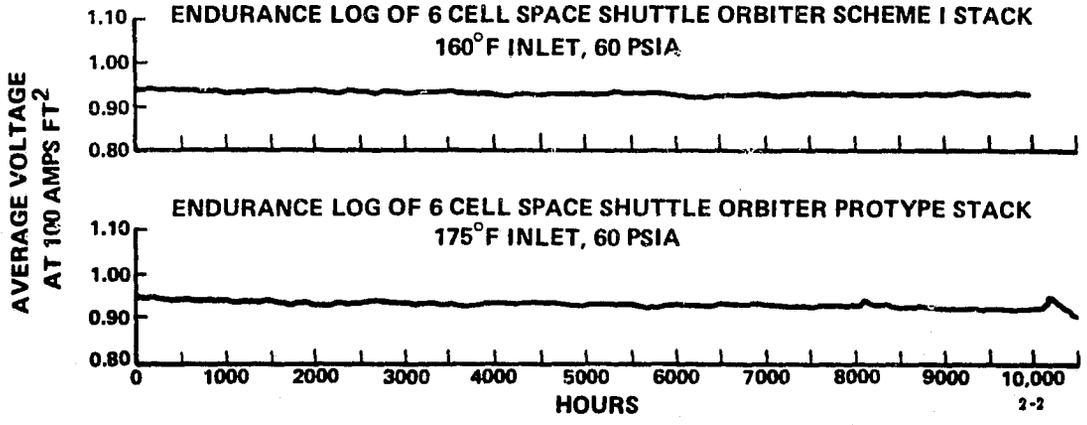


Figure 3. 10,000 Hour Power Section Tests

The X712 Demonstrator powerplant was similar to the DM-2 but incorporated a stack of 36, 0.5 $ft^2$ (464.5 $cm^2$) active area single cells with a higher performing gold-alloy cathode catalyst replacing the platinum cathode catalyst employed on the DM-2 cell. X712 has a greater capacity coolant system than the DM-2, giving it a continuous output rating of 15kW. X712 has been employed as a demonstrator powerplant for four years accumulating 115 self-energized starts.

The space shuttle PC17C powerplant incorporates two power sections comprised of 32, 0.5 $ft^2$ (464.5 $cm^2$) active area cells connected electrically in parallel. A total of 8 Orbiter fuel cell powerplants have been delivered to date, successfully completing 182 hours of operation during atmospheric testing of the Space Shuttle vehicle. The PC-17C design has accumulated over 10,147 hours of operation with over 450 self-energized starts. A PC-17C development powerplant which operated to a power profile for over 4200-hours, Figure 4, exceeding the 2,000-hour, 27.5 volt design requirement.

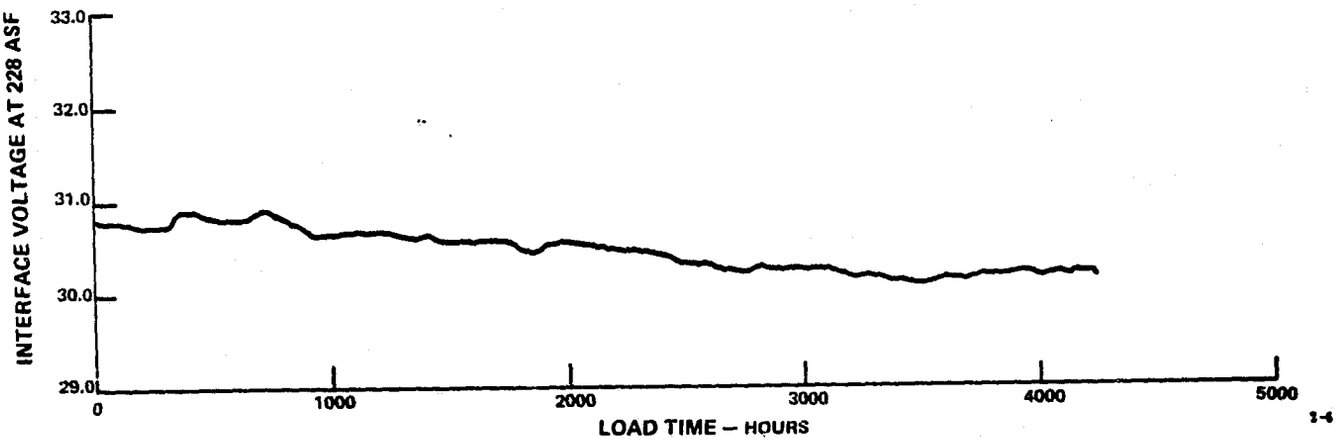


Figure 4. PC-17C Development Powerplant X-706 Test Summary

In addition a 64-cell PC-17C power section completed 3500-hours of operation to a simulated Orbiter power profile exceeding the 2,000-hour, 27.5 design voltage requirement.

An Advanced Lightweight Alkaline Fuel Cell Technology program conducted by PSD under the direction of the Lewis Research Center has identified and demonstrated a low weight cell design with increased performance and extended life.

- The lightweight cell design has a specific weight of 4 lbs/kW (1.89g/W) compared to the PC-17C cell design specific weight of 8 lbs/kW (3.69g/W).
- A gold-platinum catalyst cathode was developed which demonstrated increased cell performance and improved stability for long life.

- The lightweight cell design has accumulated over 138,000 cell-hours of operation with one cell operating continuously for 10,021 hours and another cell operating at a current density of 200 AMPS/ft$^2$ (215.3 mA/cm$^2$) for 6,680-hours.

PSD has been conducting a program under the direction of George C. Marshall Space Flight Center since March 1974 to develop a fuel cell powerplant design based upon the advanced lightweight alkaline fuel cell developed under the Lewis Research Center program.

Scope

The objective of this program was to define the design of a generic fuel cell powerplant which will meet the requirements of future NASA missions. The design will be based upon the advanced lightweight future fuel cell developed in previous programs by NASA. Ancillary components shall be similar to Space Shuttle Orbiter Powerplant components to minimize eventual delta qualification requirements.

The design shall be substantiated, and the readiness of the technology for development will be demonstrated by testing of powerplant elements, components, and sub-sections.

Relevance/Significance

Performance and endurance testing of the two-cell module configuration, repeating unit of the lightweight fuel cell power section has shown:

- The configuration will satisfy the 2500-hour voltage requirements of the Lightweight Fuel Cell Powerplant design.
- The capability to operate on propellent purity reactants with only a slight affect on cell performance.

Purpose/Objective

An analytical and experimental development effort was conducted to translate the lightweight fuel cell technology resulting from the Lewis Research Center program into a lightweight powerplant design to satisfy future NASA mission requirements. A lightweight powerplant design was developed which incorporated a 34, 0.25 ft$^2$ (232.3 cm$^2$) active area cell power section, comprised of 16 repeating two-cell modules.

Four, two-cell modules were fabricated and endurance tested to verify the power section design.

Three, 0.25 ft$^2$ (232.3 cm$^2$) active area single cells were fabricated and endurance tested to establish the increased reactant operating pressure capability of a modified lightweight cell design.