FACILITY FORM 602

N71-18432 (ACCESSION NUMBER)

25 (PAGES)

TMX-66896 (NASA CR OR TMX OR AD NUMBER)

(THRU)

G3 (CODE)

31 (CATEGORY)

GEORGE C. MARSHALL SPACE FLIGHT CENTER

SPACE SHUTTLE ENGINE

ELDO/NASA SPACE TRANSPORTATION SYSTEM BRIEFING

JULY 7 - 8, 1970 - BONN, GERMANY

Speaker

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

HUNTSVILLE, ALABAMA

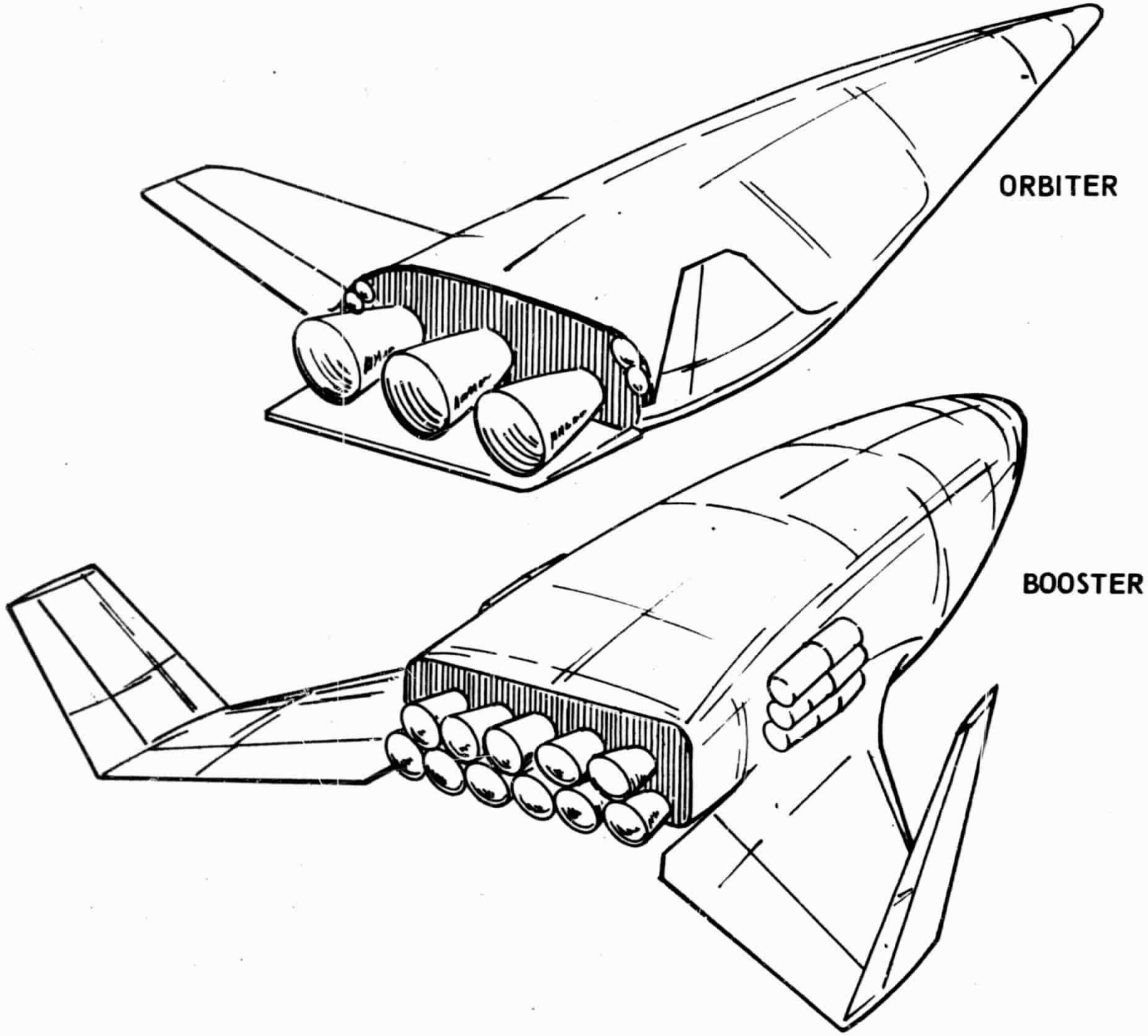
MSFC - Form 454-1 (Rev October 1967)

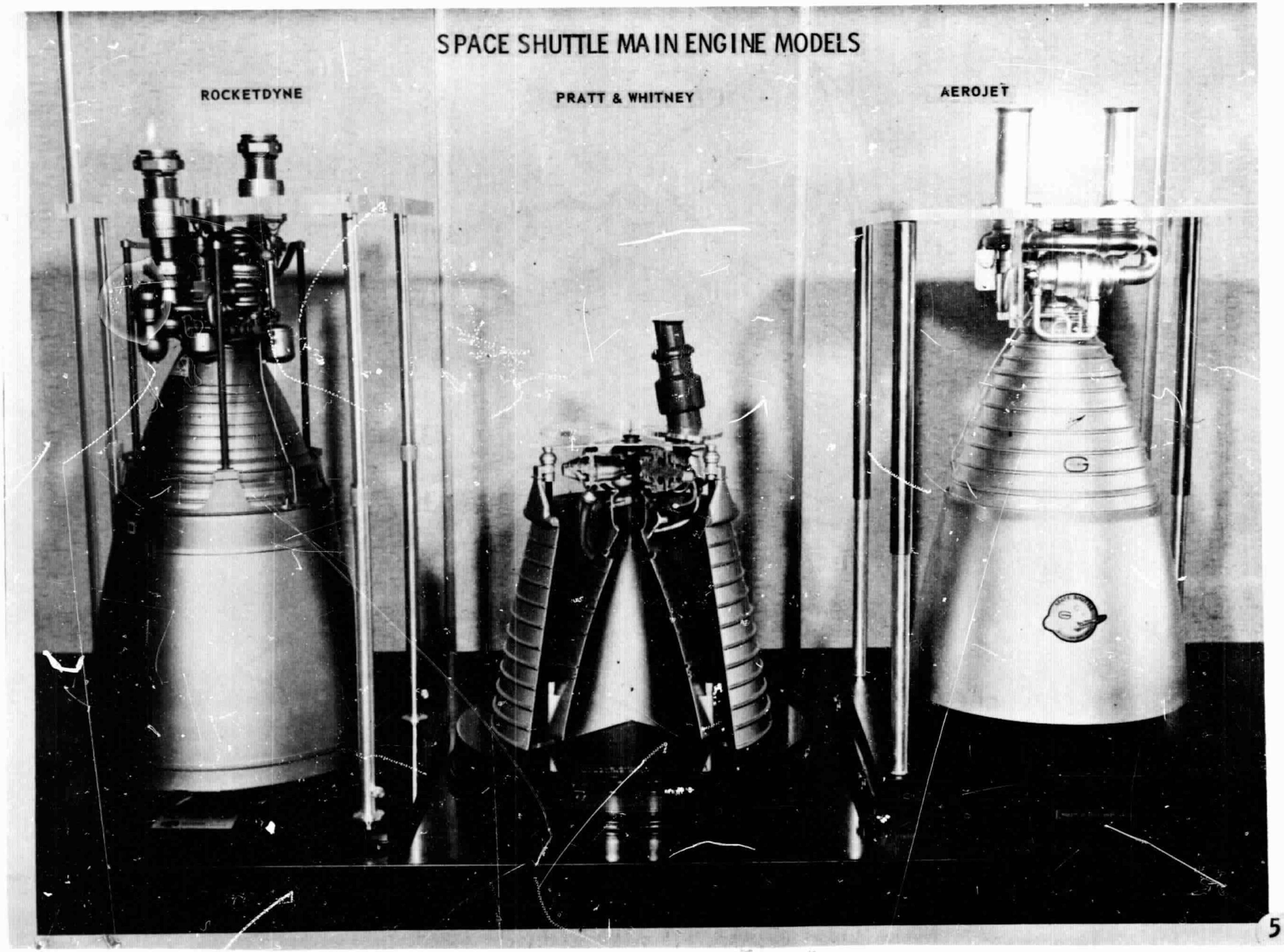
OUTLINE

INTRODUCTION

THE ROCKET ENGINES FOR BOTH THE BOOSTER AND ORBITER ELEMENTS OF THE SPACE SHUTTLE WILL BE THROTTLEABLE HIGH PERFORMANCE HYDROGEN/OXYGEN ENGINES. DEPENDING ON THE DESIGN, THE ORBITER MAY USE TWO OR THREE ENGINES WHILE THE BOOSTER MAY REQUIRE TEN OR MORE. AS IS THE CASE WITH MOST SPACE VEHICLE LAUNCH SYSTEMS, THE PACING ITEM IS THE ENGINE. THIS PAPER DESCRIBES THE SPACE SHUTTLE MAIN ENGINE REQUIREMENTS AND CONCEPTS, AND THE APPROACH TO DEVELOPMENT AS PRESENTLY ENVISIONED.

TYPICAL SPACE SHUTTLE MAIN ENGINE APPLICATION




SPACE SHUTTLE MAIN ENGINE MODELS
ROCKETDYNE
PRATT & WHITNEY
AEROJET

- REQUIREMENTS (PRELIMINARY)

THRUST (SEA LEVEL)		1, 800, 000 NEWTONS
SPECIFIC IMPULSE		
BOOSTER	SEA LEVEL	3756 NEWTON - SEC/KILOGRAM
BOOSTER	VACUUM	4335 NEWTON - SEC/KILOGRAM
ORBITER	VACUUM	4501 NEWTON - SEC/KILOGRAM
GIMBAL ANGLE		7 DEGREES
BURN TIME (NORMAL)		$\approx$ 300 SECONDS
TIME TO OVERHAUL		$>$ 10 HOURS OR 100 STARTS
MIXTURE RATIO (OXYGEN/FUEL)		6. 0
CHAMBER PRESSURE		2000 NEWTONS /cm^2

CHARACTERISTICS

REUSABLE AND RELIABLE - OUR PREVIOUS LARGE ROCKET ENGINES WERE REQUIRED TO MAKE ONLY ONE FLIGHT, AFTER WHICH THEY DROPPED IN THE OCEAN OR BURNED UP AT RE-ENTRY. THE SHUTTLE ROCKET ENGINE MUST PERFORM IN AN AIRLINE MODE AND OPERATE FOR 10 HOURS AT THE NORMAL POWER LEVEL, ACCOMPLISHING APPROXIMATELY 100 FLIGHTS BEFORE OVERHAUL.

COST EFFECTIVE - THE ENGINES FOR THE BOOSTER AND THE ORBITER WILL BE ESSENTIALLY COMMON FROM THE PUMP INLETS TO A POINT APPROXIMATELY .5 METERS BELOW THE INJECTOR, WHICH IS JUST A LITTLE BELOW THE THROAT. THE THRUST CHAMBER MAY BE CONFIGURED DIFFERENTLY BECAUSE OF ALTITUDE CONSIDERATIONS, AND THE ORBITER WILL HAVE A RETRACTABLE SKIRT. WHILE THIS IS A MORE DIFFICULT DEVELOPMENT TASK THAN WE HAVE ACCOMPLISHED IN THE PAST, OUR GOAL IS TO COMPLETE IT AT CONSIDERABLY LESS COST. WE WILL ACCOMPLISH THIS BY DEVELOPING COMPETITION BETWEEN CONTRACTORS, EXPANDING THE COMPONENT TEST PROGRAM TO REDUCE SYSTEM TEST REQUIREMENTS, AND DESIGNING FOR ECONOMY IN OPERATIONAL AND MAINTENANCE PROGRAMS, AS WELL AS HARDWARE COSTS.

WEIGHT AND SIZE - THE BOOSTER ENGINE WILL BE APPROXIMATELY 3.6 METERS TALL AND 1.9 METERS IN DIAMETER. THE ORBITER ENGINE WITH THE SKIRT EXTENDED WILL BE APPROXIMATELY 5.8 METERS TALL AND 3.6 METERS IN DIAMETER. A STANDARD ENGINE WILL WEIGH APPROXIMATELY 2200 KILOGRAMS. WITH ALL THE ACCESSORIES, SUCH AS GIMBAL ACTUATORS, AUXILLIARY POWER UNITS AND ACCUMULATORS, THE WEIGHT WILL INCREASE TO APPROXIMATELY 3200 KILOGRAMS.

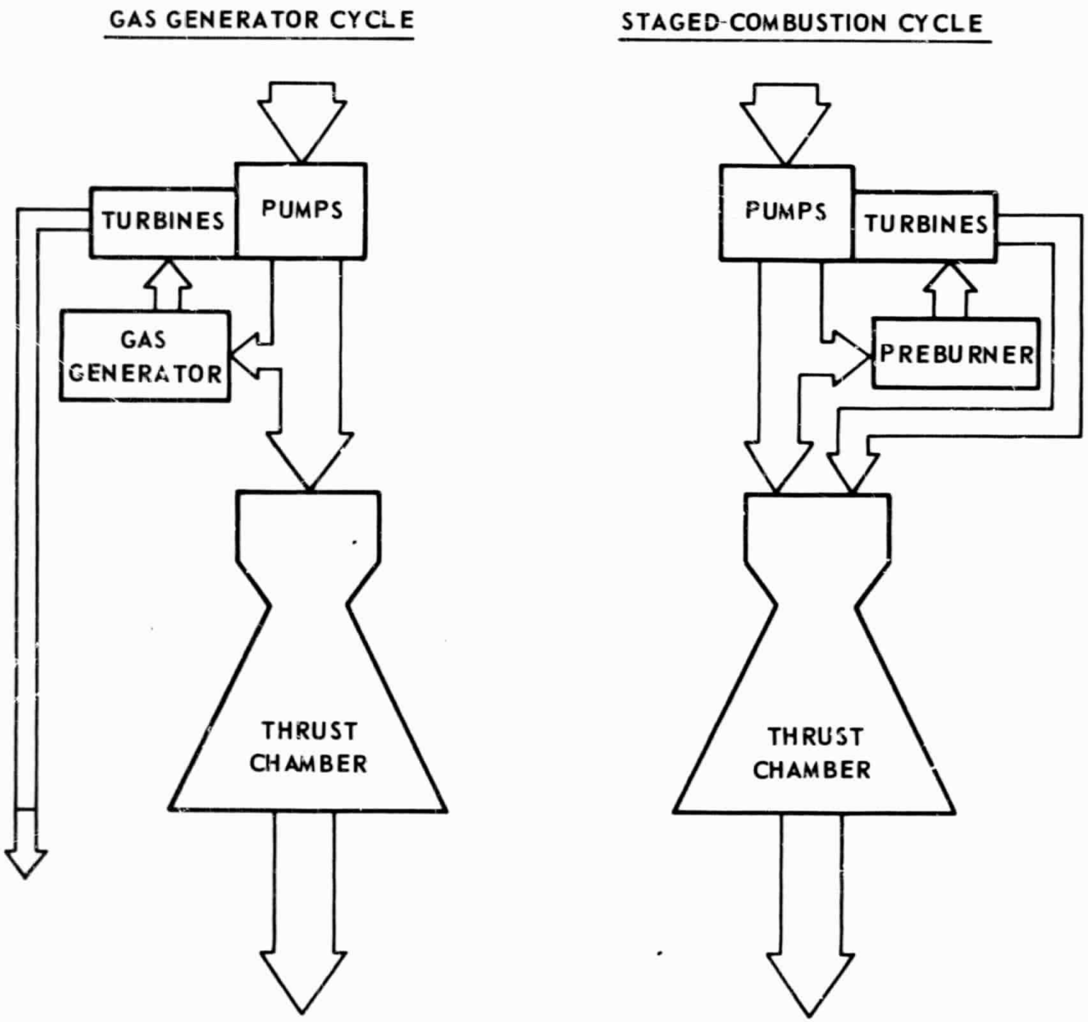
- CHARACTERISTICS
  - REUSABLE & RELIABLE
  - COST EFFECTIVE
  - STAGED COMBUSTION

THE GAS GENERATOR CYCLE SHOWN ON THE LEFT DEPICTS THE TIME HONORED METHOD OF PROVIDING POWER TO THE TURBINES WHICH DRIVE THE PROPELLANT PUMPS. A PORTION OF THE OXIDIZER AND FUEL IS TAPPED FROM THE DISCHARGE LINES OF THE PUMPS AND COMBUSTED IN THE GAS GENERATOR. AFTER DRIVING THE TURBINES, THE HOT GAS FROM THE GAS GENERATOR IS DUCTED TO A LOW PRESSURE AREA OF THE THRUST CHAMBER (BELOW THE THROAT) OR DUMPED OVERBOARD. IN SOME CASES, THIS GAS IS EJECTED THROUGH A SWIVELLING NOZZLE WHICH IS USED FOR CONTROLLING ROLL OF THE VEHICLE. CERTAIN PERFORMANCE LOSSES ARE EXPERIENCED IN THIS CYCLE DUE TO THE LOW PERFORMANCE (SPECIFIC IMPULSE) OBTAINED FROM THE PROPELLANTS USED IN THE GAS GENERATOR.

THE STAGED-COMBUSTION CYCLE SHOWN ON THE RIGHT ELIMINATES THE PERFORMANCE PENALTY SUFFERED BY THE GAS GENERATOR CYCLE, BY ROUTING 100% OF THE PROPELLANTS TO THE COMBUSTION CHAMBER WHERE THEY CAN BE COMBUSTED AT HIGH EFFICIENCY AND EXPANDED THROUGH THE THRUST CHAMBER NOZZLE. POWER FOR THE PUMP TURBINES IS PROVIDED BY HOT GAS FROM THE PREBURNER(S). ALTHOUGH THIS CYCLE PROVIDES HIGHER PERFORMANCE, IT REQUIRES HIGHER PUMP DISCHARGE PRESSURES BECAUSE THE DROP IN PRESSURE EXPERIENCED IS THROUGH THE PREBURNER TURBINE SERIES CIRCUIT.

IN PRACTICE, THE PREBURNERS ARE OPERATED AT A MIXTURE RATIO OF APPROXIMATELY 1 IN ORDER TO KEEP THE TEMPERATURE OF THE HOT GAS LOW ENOUGH TO BE COMPATIBLE WITH THE MATERIAL PROPERTIES OF THE TURBINES. APPROXIMATELY 85% OF THE HYDROGEN AND 15% OF THE OXYGEN ARE ROUTED TO THE PREBURNER(S). THE BALANCE OF THE PROPELLANTS GO TO THE THRUST CHAMBER WHERE THE HYDROGEN-RICH HOT GAS FROM THE PREBURNER(S) IS COMBUSTED WITH THE MAJOR PORTION OF THE OXYGEN.

SPACE SHUTTLE ENGINE COMBUSTION CYCLE



PROPOSED SPACE SHUTTLE ENGINE FEATURES

- PRATT & WHITNEY
  - STAGED COMBUSTION
  - SINGLE PREBURNER
  - INTEGRAL BOOST PUMP
  - TRANSPIRATION COOLED COMBUSTION CHAMBER AND REGENERATIVELY COOLED NOZZLE

- ROCKETDYNE
  - STAGED COMBUSTION
  - DUAL PREBURNER
  - INTEGRAL BOOST PUMP
  - REGENERATIVELY COOLED COMBUSTION CHAMBER AND NOZZLE

- AEROJET
  - STAGED COMBUSTION
  - DUAL PREBURNER
  - VEHICLE MOUNTED BOOST PUMP (POSSIBLE REMOTE)
  - REGENERATIVELY COOLED COMBUSTION CHAMBER AND NOZZLE

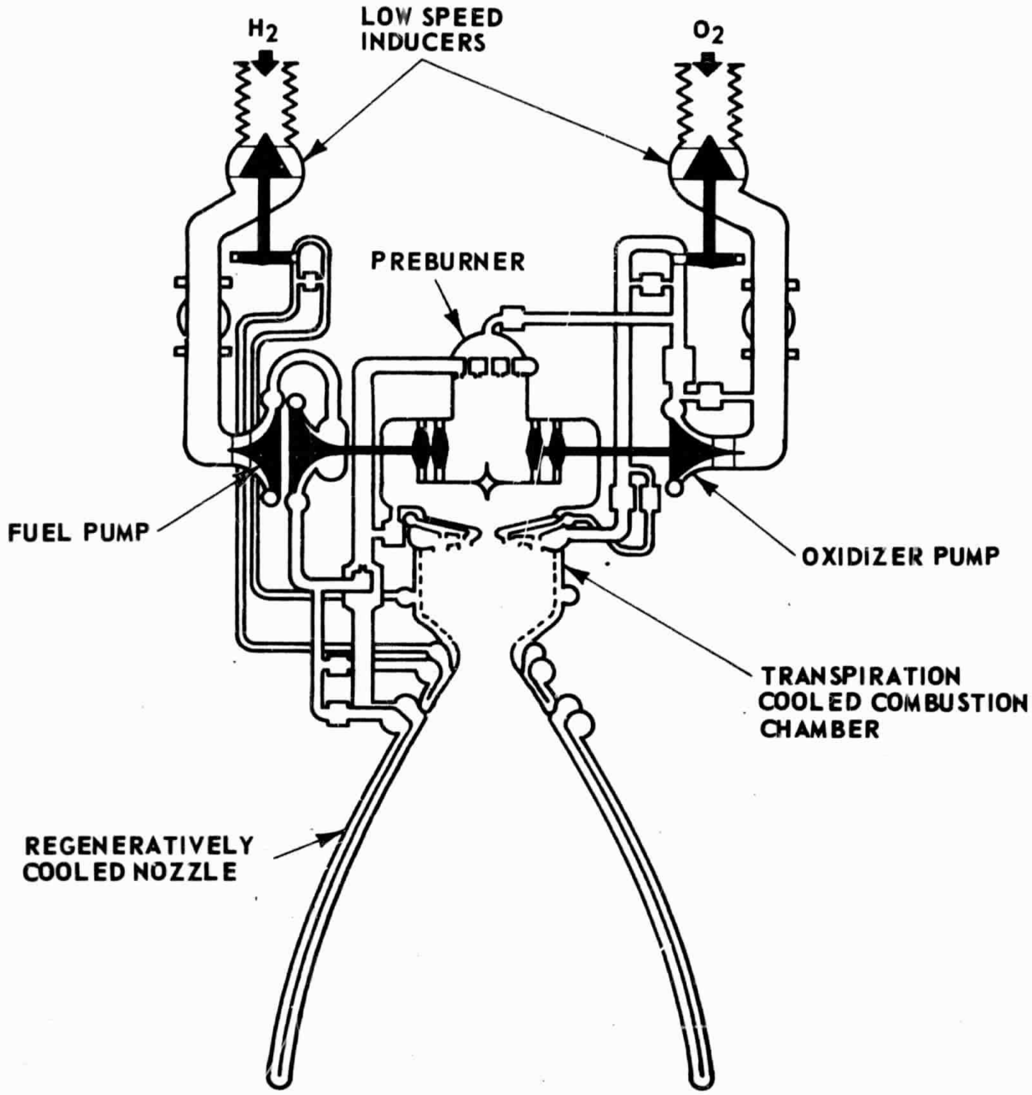
THE PRATT & WHITNEY AIRCRAFT SPACE SHUTTLE ENGINE (SSE) IS A STAGED COMBUSTION, HIGH PRESSURE 2.07×10^7 N/m^2 (3000 psia), VARIABLE THRUST (2:1), ROCKET ENGINE UTILIZING LIQUID OXYGEN AND LIQUID HYDROGEN AS PROPELLANTS. THE ENGINE IS CAPABLE OF OPERATING AT A NORMAL POWER LEVEL (NPL) RATED SEA LEVEL THRUST OF 1.777×10^6 N/m^2 (400,000 LBS) WHEN FITTED WITH A NOZZLE OPTIMIZED FOR BOOSTER STAGE APPLICATION, AND AN EMERGENCY POWER LEVEL (EPL) OF 2.10×10^6 N/m^2 (469,300 LBS) SEA LEVEL THRUST. THE ENGINE IS CAPABLE OF OPERATION OVER AN OXIDIZER TO FUEL MIXTURE RATIO RANGE OF 5.5 TO 6.5 INCLUDING TANK PRESSURIZATION FLOWS, BETWEEN MINIMUM AND NOMINAL. ALTERNATE EXHAUST NOZZLES MAY BE ADAPTED TO A BASIC POWER HEAD ASSEMBLY TO OPTIMIZE THE ENGINE FOR EITHER BOOSTER OR ORBITER STAGE APPLICATIONS.

GASEOUS HYDROGEN AND OXYGEN MAY BE BLED FROM THE ENGINE TO PROVIDE VEHICLE TANK PRESSURIZATION. A HEAT EXCHANGER TO HEAT VEHICLE-SUPPLIED HELIUM CAN BE PROVIDED AS AN ALTERNATE SYSTEM FOR OXIDIZER TANK PRESSURIZATION. THRUST VECTOR CONTROL (TVC) IS PROVIDED BY AN ENGINE-SUPPLIED TVC SYSTEM WHICH WILL GIMBAL THE ENGINE IN RESPONSE TO EXTERNAL COMMAND INPUTS. THE ENGINE MAY BE GIMBALED IN A $\pm$ 7 DEGREE SQUARE PATTERN FOR TVC.

ENGINE DURABILITY IS CHARACTERIZED BY 10 HOURS OPERATING TIME AND 100 FIRINGS BETWEEN OVERHAULS. THE MODULAR PLUG-IN COMPONENT CONCEPT PROVIDES EASE OF ACCESS AND OVERHAUL.

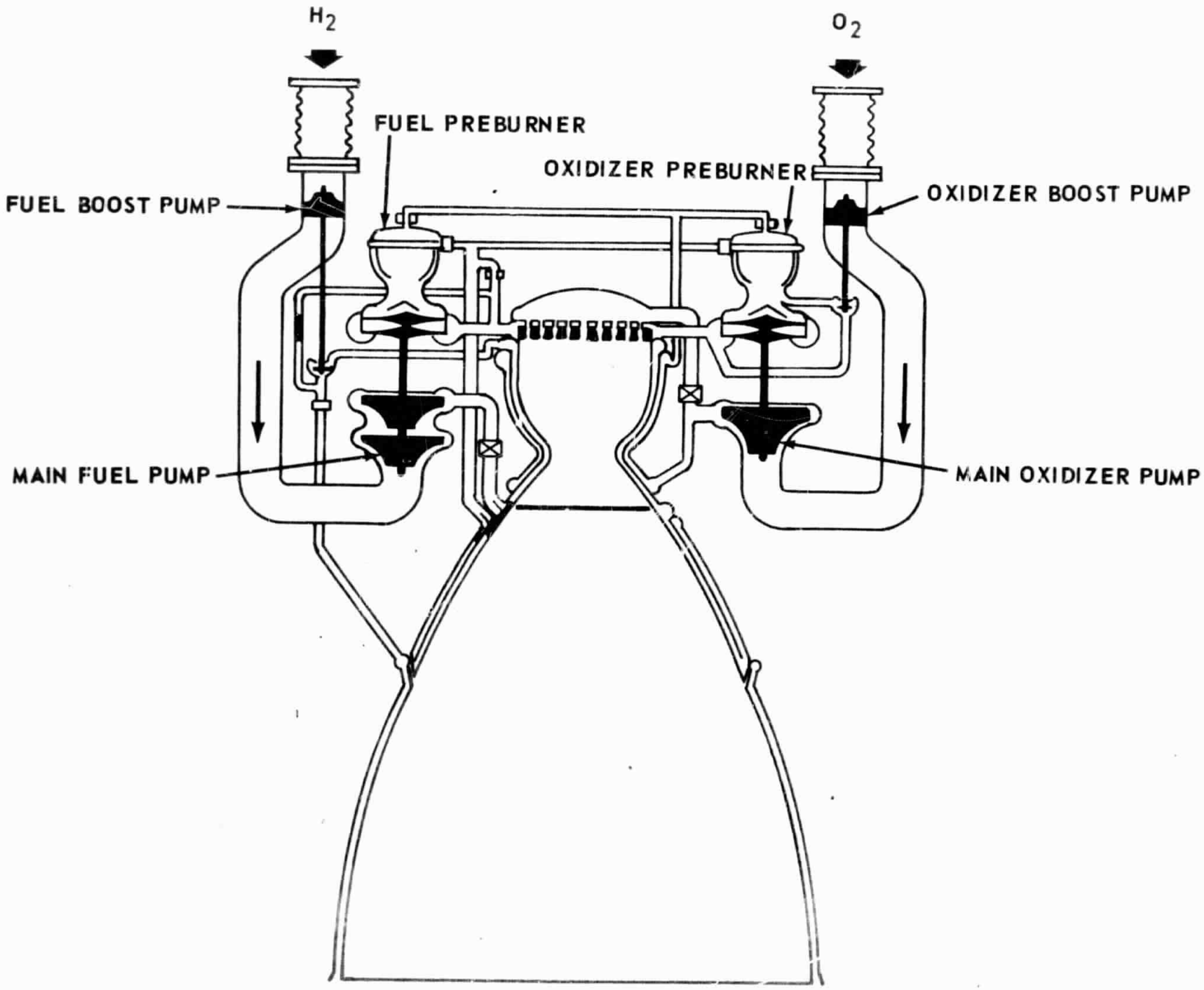
THE BASELINE SSE CONFIGURATION IS A SINGLE-PREBURNER, STAGED-COMBUSTION CYCLE, WITH A TWO-STAGE UNSHROUDED CENTRIFUGAL FUEL PUMP, AND A SINGLE-STAGE SHROUDED CENTRIFUGAL OXIDIZER PUMP. FUEL AND OXIDIZER LOW-SPEED INDUCERS UPSTREAM OF THE MAIN PUMPS ARE USED TO MINIMIZE VEHICLE TANK PRESSURE REQUIREMENTS. THE MAIN FUEL AND OXIDIZER PUMPS ARE DRIVEN BY EXPANSION OF 3.45×10^7 N/m^2 (5000 psia) PREBURNER COMBUSTION PRODUCTS THROUGH AXIAL FLOW TURBINES. MAIN BURNER PROPELLANTS ARE THE FUEL-RICH TURBINE EXHAUST PRODUCTS AND THE OXIDIZER FLOW WHICH IS NOT REQUIRED BY THE PREBURNER FOR TURBINE POWER. THE MAIN COMBUSTION CHAMBER WALL IS TRANSPIRATION-COOLED BY HYDROGEN FLOW THROUGH A LINER COMPOSED OF COPPER WAFERS EXTENDING FROM THE INJECTOR FACE TO AN AREA RATIO OF 6.0. PRIMARY NOZZLE COOLING IS OBTAINED BY ROUTING FUEL FLOW THROUGH TUBULAR NOZZLE MAIN CHAMBER. TO MINIMIZE ENGINE STOWED LENGTH AND HIGH AREA RATIO NOZZLE WEIGHT, A LIGHTWEIGHT DUMP-COOLED, TWO-POSITION, MINIMUM STOWED LENGTH NOZZLE IS USED FOR THE ORBITER ENGINE.

PRATT & WHITNEY SHUTTLE MAIN ENGINE SCHEMATIC



THIS SCHEMATIC DRAWING IS A REPRESENTATION OF THE SPACE SHUTTLE MAIN ENGINE CONCEPT PROPOSED BY THE ROCKETDYNE DIVISION OF THE NORTH AMERICAN ROCKWELL CORPORATION. THE MAIN THRUST CHAMBER OPERATES AT A COMBUSTION PRESSURE OF APPROXIMATELY 20.7 X 10^6 N/m^2 (3000 psi) AND IS COOLED REGENERATIVELY WITH HYDROGEN. A PORTION OF THE HYDROGEN FROM THE FUEL BOOST PUMP PASSES THROUGH THE COOLING JACKET OF THE EXTENDIBLE NOZZLE AND IS DUMPED AT THE NOZZLE EXIT. THE PROPELLANTS ARE SUPPLIED TO THE THRUST CHAMBER BY THE MAIN OXIDIZER PUMP AND THE MAIN FUEL PUMP. THE TURBINES FOR EACH OF THESE PUMPS ARE DRIVEN BY HOT GAS FROM SEPARATE PREBURNERS. AFTER THE HOT GAS IS EXPANDED THROUGH THE TURBINES, IT IS DUCTED TO THE MAIN INJECTOR. THE TWO BOOST PUMPS ARE DESIGNED TO OPERATE AT LOW SPEEDS TO ACCOMMODATE THE LOW INLET PRESSURES (NET POSITIVE SUCTION HEAD) AND INCREASE THE FLUID PRESSURE TO PERMIT HIGH-SPEED OPERATION OF THE MAIN PUMPS, WHICH DISCHARGE PROPELLANTS AT PRESSURES OF APPROXIMATELY 41.7 X 10^6 N/m^2 (6000 psi). TO FACILITATE THROTTLING, THE OXYGEN FURNISHED TO THE TWO PREBURNERS IS GASIFIED IN A HEAT EXCHANGER JACKET WHICH SURROUNDS THE MAIN COMBUSTION CHAMBER. HOWEVER, CONSIDERATION IS BEING GIVEN TO THE ELIMINATION OF THIS FEATURE BECAUSE THE THROTTLING REQUIREMENTS HAVE BEEN REDUCED FROM 10/1 TO 2/1. OTHER CHANGES BEING CONSIDERED ARE THE ADDITION OF ANOTHER STAGE TO EACH OF THE MAIN PUMPS, WHICH WILL INCREASE EFFICIENCIES AND DECREASE PUMP DISCHARGE PRESSURES.

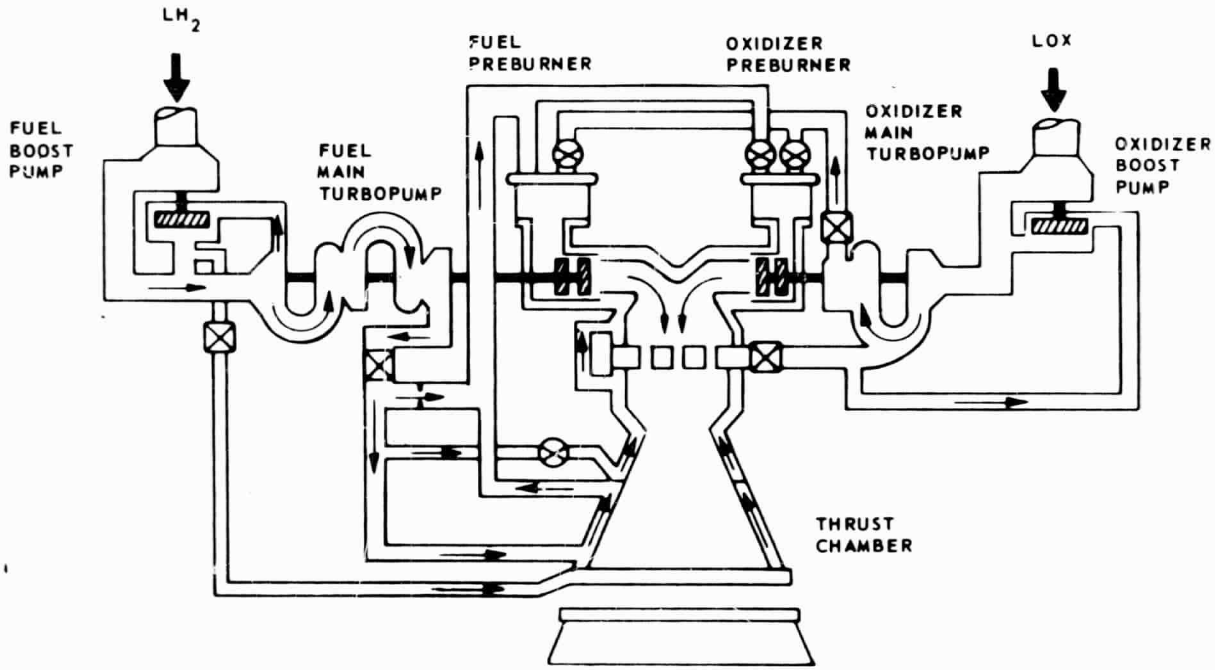
ROCKETDYNE SHUTTLE MAIN ENGINE SCHEMATIC



THE AEROJET LIQUID ROCKET COMPANY LOX/LH_2 STAGED-COMBUSTION CYCLE ENGINE IS DISTINGUISHED BY DUAL PREBURNERS, VEHICLE MOUNTED BOOST PUMPS, REGENERATIVELY COOLED THRUST CHAMBER AND NOZZLE RADIATION COOLED EXTENDIBLE NOZZLE FOR ORBITER APPLICATION, A THREE-STAGE CENTRIFUGAL FUEL MAIN TURBOPUMP, AND A 1 - 1/2 STAGE OXIDIZER MAIN TURBOPUMP.

THE SCHEMATIC SHOWN REPRESENTS THE MAJOR ENGINE FLOW CIRCUITS. BOTH PROPELLANTS ENTER LOW-SPEED BOOST PUMPS DRIVEN BY RECIRCULATING FLOW FROM THE MAIN TURBOPUMPS. EXCEPT FOR ORBITER NOZZLE EXTENSION COOLANT FLOW (ABOUT 2%), ALL THE FUEL PASSES THROUGH THE MAIN TURBOPUMP. PART OF THIS FLOW IS USED TO REGENERATIVELY-COOL THE COMBUSTION CHAMBER AND THE GAS MANIFOLD (ABOUT 11%). IT IS DISCHARGED INTO THE TURBINE EXHAUST. ANOTHER PART OF THE FUEL (ABOUT 28%) REGENERATIVELY COOLS THE THRUST CHAMBER NOZZLE, THEN IT REJOINS AND MIXES WITH THE REMAINING FUEL (56%) GOING TO THE PREBURNERS. A MODULATING VALVE IN THE COMBUSTION CHAMBER COOLANT LINE DECREASES RESISTANCE WITH DECREASING THRUST TO MAINTAIN ADEQUATE FLOW. TEMPERATURES IN THE PREBURNERS ARE EQUALIZED BY A MODULATING VALVE IN THE OXIDIZER PREBURNER FUEL LINE. OXIDIZER FLOWS THROUGH THE FIRST STAGE OF THE MAIN TURBOPUMP TO FEED THE MAIN INJECTOR, THE BOOST PUMP DRIVE, THE OXIDIZER TANK PRESSURANT HEAT EXCHANGER, AND THE SECOND-STAGE OF THE OXIDIZER PUMP, WHICH, IN TURN, SUPPLIES THE PREBURNERS. FUEL-RICH COMBUSTION GASES FROM THE PREBURNERS DRIVE THE MAIN PUMP TURBINES. TURBINE POWER IS ADJUSTED WITH THE MODULATING OXIDIZER PREBURNER VALVES. SYNCHRONOUS MODULATION OF THE VALVES CONTROLS THRUST WHILE DIFFERENTIAL MODULATION CONTROLS MIXTURE RATIO. THE TURBINE EXHAUST GASES ARE REACTED WITH THE MAIN INJECTOR OXIDIZER IN THE COMBUSTION CHAMBER.

AEROJET SHUTTLE MAIN ENGINE FLOW DIAGRAM



TECHNOLOGY BASE

- DURING THE LAST FIVE YEARS WE HAVE SUCCESSFULLY EXECUTED THE FOLLOWING TECHNOLOGY INVESTIGATIONS AT OPERATING CONDITIONS CONSISTENT WITH SHUTTLE ENGINE REQUIREMENTS:
    - STAGED COMBUSTION CYCLE ANALYSIS AND TESTING
    - DESIGN AND TEST FULL SCALE PUMPS (4000 N/cm^2)
    - TRANSPIRATION COOLING OF THRUST CHAMBERS
    - REGENERATIVE COOLING OF THRUST CHAMBERS
    - EFFICIENT COMBUSTION OF HYDROGEN AND OXYGEN

- DEFINITION PLAN - MAJOR OBJECTIVES
  - PROTOTYPE ENGINE DESIGN
  - PARAMETRIC STUDIES
  - LIMITED EXPERIMENTAL TESTING
  - SELECTION OF CONTRACTORS

PARAMETRIC ANALYSIS

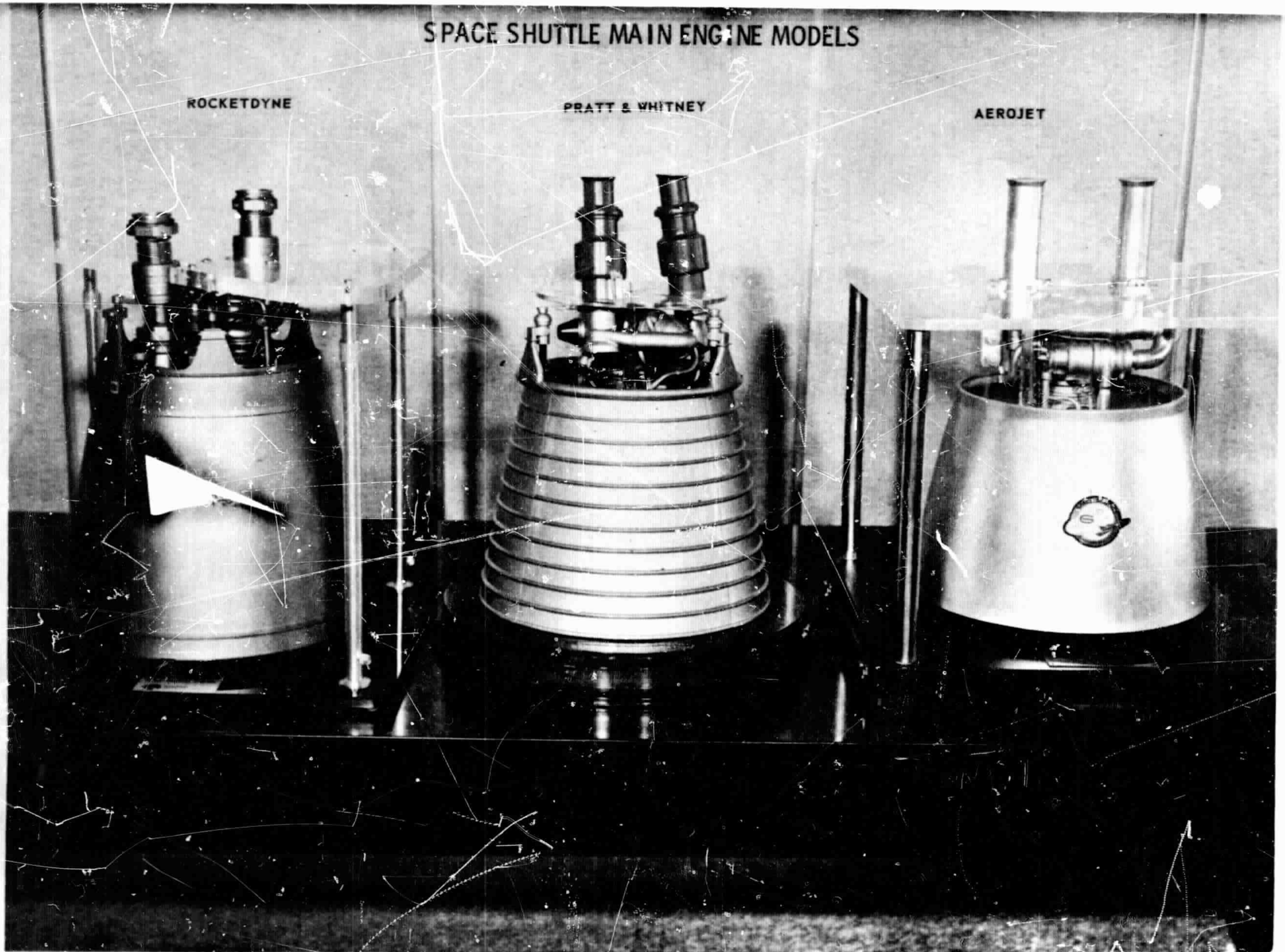
- DETERMINE THE EFFECT ON COST AND COMPLEXITY OF VARIATION IN MAJOR PARAMETERS, SUCH AS:

THRUST	1110 kN, 1800 kN, 2670 kN
EMERGENCY POWER LEVEL	125%
NUMBER OF STARTS	100, 500, 1000
LIFETIME	5, 10, 20 HOURS
ALTITUDE RESTART	RESTART VS NO RESTART
THROTTLE RANGE	5%, 10%, 20%, 50%
NOZZLE OPTIMIZATION	COMMON CONTOUR VS TAILORED

SUMMARY

- STARTED 11 MONTH DEFINITION CONTRACT WITH THREE CONTRACTORS IN JUNE 1970

- WE HAVE HIGH CONFIDENCE THAT THE SPACE SHUTTLE ENGINE CAN MEET COST, SCHEDULE AND PERFORMANCE GOALS TO SATISFY OVERALL SHUTTLE PROGRAM OBJECTIVES


SPACE SHUTTLE MAIN ENGINE MODELS
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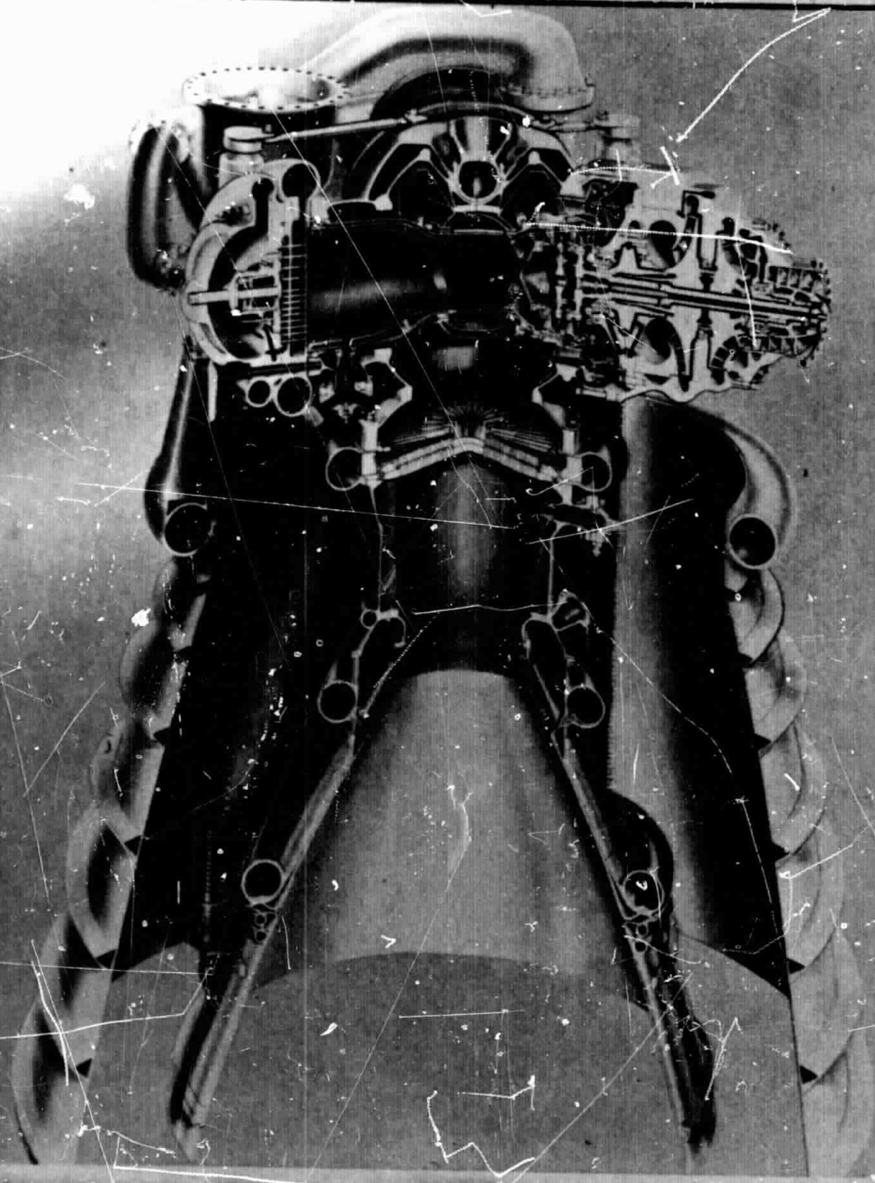
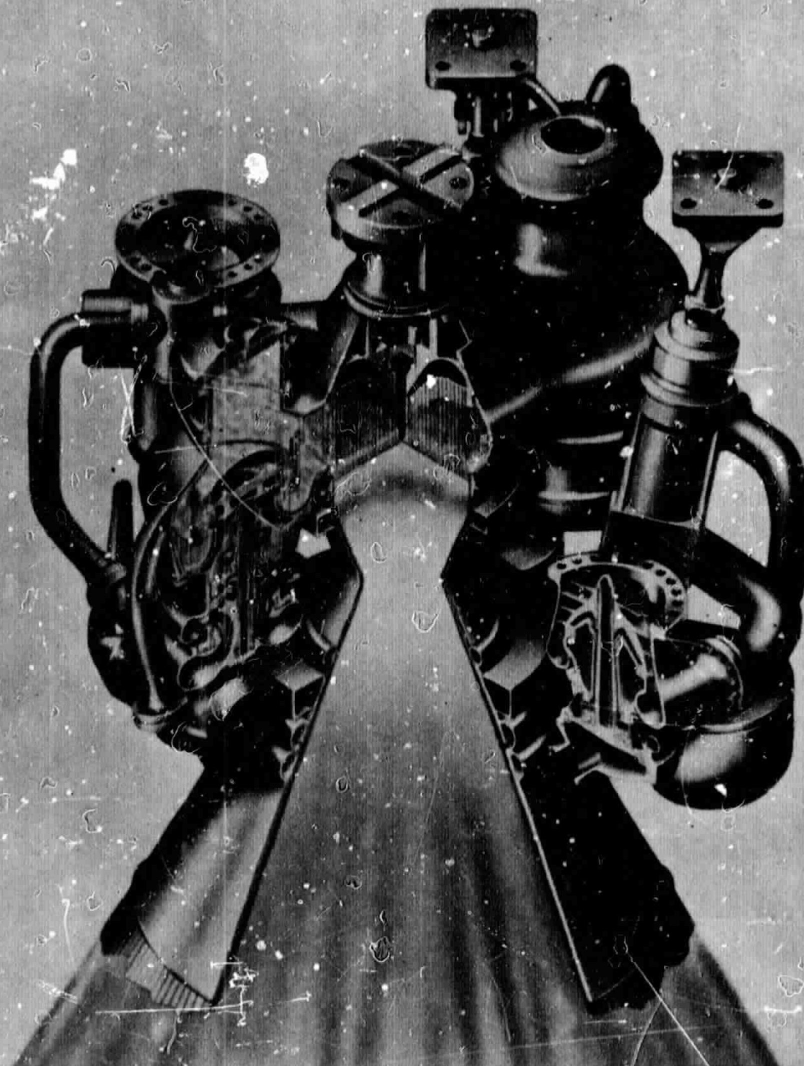
PRATT & WHITNEY SHUTTLE MAIN ENGINE



ROCKETDYNE SHUTTLE MAIN ENGINE



AEROJET SHUTTLE MAIN ENGINE