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CNLM-2240
January 8, 1960

Classification cancelled (~~or changed to~~)
by authority of
by ~~R.R.~~ H.F.C. TIC, date ~~Date~~ SEP 17 1973
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PRATT & WHITNEY AIRCRAFT NUCLEAR J58 TURBOJET ENGINE POWERPLANT CHARACTERISTICS SUMMARIES

The engine performance and powerplant description of various propulsion systems are presented below. Included are data for variations of the J58 engine with 1600F NaK, 1800F NaK and 2000F lithium radiators. The information presented herein does not include reactor and shield data.

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A. Powerplant Performance

Performance of the Pratt & Whitney Aircraft J58 turbojet engine coupled to lithium-cooled reactors has been estimated for an envelope of operating flight conditions. The results are presented in a series of reports, FXD-460 to FXD-467. Performance calculations have been made for nuclear heat operation and for nuclear-chemical operation of the J58 engine with three different liquid metal conditions, 1600F NaK, 1800F NaK and 2000F lithium, entering the engine radiators.

Engine performance is computed for the ARDC standard atmosphere with an inlet total pressure recovery equal to 100 percent for flight speeds less than Mach 1. At speeds greater than Mach 1, the inlet total pressure recovery equals $1.0-0.045\ (M-1.0)^{1.5}$. It has been assumed that there is no loading of the engine accessories and no bleed air. Allowance has been made, however, for the power required to drive the liquid metal pumps which operate on air bled from the engine at radiator discharge.

1. 1600F NaK Radiator

Data for operation at maximum and at part-load nuclear heat is presented for the J58 engine with a 1600F NaK radiator in FXD-460. The data includes net thrust, airflow and heat input. The net thrust includes the thrust from auxiliary nozzles which discharge the air bled for the pump-turbine-drives.

The auxiliary nozzle thrust, airbleed, compressor and radiator exit temperatures and pressures, exhaust nozzle temperatures and pressure ratios, and thrust correction factors are presented for maximum nuclear heat operation in FXD-467. The use of these correction factors is described later in this report.

~~CLASSIFICATION CHANGED TO CONFIDENTIAL~~
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~~H.F. Carroll~~
~~Chief, Declassification Branch~~

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Nuclear-chemical performance of the J58 engine is presented in FXD-464. For this mode of operation, net thrust, TSFC, airflow and reactor power have been plotted for maximum afterburning operation with thrust and TSFC corrections for partial afterburning. The airflow and reactor power do not change for partial afterburning.

2. 1800F NaK Radiator

Performance similar to that prepared for the J58 engine with a 1600F NaK radiator has been prepared for the engine with an 1800F NaK radiator. The nuclear heat operation data is contained in FXD-461 and FXD-462. The nuclear-chemical data is contained in FXD-465.

3. 2000F Lithium Radiator

Data for part-load nuclear heat operation and thrust correction factors have not been computed for the J58 engine with a 2000F lithium radiator. Otherwise the presentation is the same as for the other two radiators described above. Maximum nuclear heat operation is presented in FXD-463; nuclear-chemical operation is presented in FXD-466.

4. Correction Factors

Correction factors based on "with loss" cycle calculations are presented for use in correcting engine performance for:

(1) Duct pressure loss
(2) Compressor exit airbleed
(3) Radiator exit airbleed
(4) Power extraction
(5) Ambient temperature variation

The effect of these losses on thrust and airflow is obtained by multiplying the loss by the appropriate correction factor using the following equation:

$$\frac{\Delta F}{F} = (1 + C_D)\frac{\Delta P}{P_2} + C_D\frac{\Delta P}{P_7} - C_{bc}\frac{W_{bc}}{W} - C_{br}\frac{W_{br}}{W} - C_{px}\frac{HP}{10{,}000} - C_{am}\frac{\Delta t_{am}}{t_{am}}$$

$$\frac{\Delta W}{W} = \frac{\Delta P}{P_2} - C'_{bc}\frac{W_{bc}}{W} - C'_{br}\frac{W_{br}}{W} - C'_{px}\frac{HP}{10{,}000} - \frac{\Delta t_{am}}{t_{am}}$$

where C_D = thrust correction factor for duct loss

C_{bc} = thrust correction factor for compressor exit airbleed

C_{bc}' = airflow correction factor for compressor exit airbleed

C_{br} = thrust correction factor for radiator exit airbleed

C_{br}' = airflow correction factor for radiator exit airbleed

C_{px} = thrust correction factor for power extraction

C_{px}' = airflow correction factor for power extraction

C_{am} = thrust correction factor for ambient temperature variation

F = net thrust

HP = shaft power extracted

P_2 = compressor inlet total pressure

P_7 = nozzle total pressure

t_{am} = ambient air temperature

W = total engine airflow

W_{bc} = compressor exit airbleed

W_{br} = radiator exit airbleed

Correction factors have not been computed for the engine operating with a 2000F lithium radiator. The performance of the engine may be corrected for non-standard conditions using the correction factors presented for the 1800F NaK radiator engine. Also, correction factors have not been estimated for any of the radiators during nuclear-chemical operation. For this mode of operation, the correction factors presented in the specifications and installation handbook of the chemical J58 engine should be used.

B. Powerplant Description

A solid fuel element reactor constructed of a columbium alloy supplies the heat to the powerplant. The heat is removed from the reactor by lithium in a primary liquid metal circuit and, for the 1600F and 1800F NaK radiator cases, is transferred to NaK in a secondary circuit via an intermediate heat exchanger. In the 2000F lithium radiator case, the lithium is piped directly from the reactor to the engine radiator. All structural materials in the lithium circuits are columbium alloy, and those in the NaK circuit are type 316 stainless steel.

1. Liquid Metal Piping Schematic

A schematic drawing showing the layout of a single reactor, two loop powerplant is illustrated in Fig 1. The system is characterized by six independent NaK loops. A similar schematic for a single reactor, single loop powerplant is shown in Fig 2. In this powerplant, isolation valves are required for each engine radiator. The piping schematic of a twin reactor, two loop powerplant is shown in Fig 3.

2. Powerplant Weight Estimates

The estimated weight of a nuclear powerplant exclusive of reactor and shield, for each of the three engine radiator cases is tabulated in Fig 4. The tabulation is based on six engine, single reactor powerplants. Weight corrections for twin reactor arrangements are given.

3. Piping Data

The weights and dimensions of the liquid metal piping and pump-turbine airbleed ducting is presented in Fig 5. Eighty feet of NaK piping and thirty feet of lithium piping were assumed for each engine with the two loop systems. Eighty feet of lithium piping per engine is assumed for the single loop system. The air duct length per engine is assumed to be 100 feet.

4. Liquid Metal Pump and Turbine Data

The liquid metal and airbleed temperatures, pressures and flow rates at the pump turbine assembly are shown in Fig 6 on a per engine bases for the 1800F NaK radiator at the cruise flight condition, Mach 0.9 and 25,000 ft altitude.

5. Shield Cooling System

A preliminary estimate of the radiator for the reactor shield coolant has been completed for the six engine, 1800F NaK radiator powerplant and is presented in Fig 7.

6. Liquid Metal Properties

The density and specific heat of lithium and NaK are plotted in Figs 8 and 9 as a function of temperature.

7. Turbojet Engine Cooling Requirements

Secondary airflow bypassed from the engine air inlet and ejected into the exhaust gas path can be used for cooling the exterior of the engine and the nozzle. The quantity of flow will amount to 3 to 4 percent of the engine airflow at maximum flight velocity.

No other specific cooling is required for the engine or components. All engine supplied components are expected to withstand ambient temperature experienced within engine operational limits.

8. Engine Oil Heat Rejection and Consumption

The nuclear J58 engine oil heat rejection is not anticipated to differ significantly from that of the chemical J58 turbojet. The latest estimated heat rejection and consumption of the chemical J58 is listed below:

(1) At Mach 0.9 and 25,000 ft altitude the total heat rejection of the engine oil is 1820 BTU per min.

(2) At Mach 0.9 and sea level, the total heat rejection of the engine oil is 2900 BTU per min.

(3) The above values are based on an engine oil inlet temperature of 550F.

(4) The slope of the curve of heat rejection versus engine oil inlet temperature is -1.4 BTU per min.

(5) The oil consumption of the engine (realistic value) is presently estimated at 0.2 gals/hr.

9. Chemical Fuel Bypass

The chemical fuel bypass and return arrangement used on the J58 engine results in some heating of the chemical fuel by pump work.

Fuel flow is required through the pumps and fuel control at all times when the engine is operating to lubricate and cool rotating parts. During nuclear heat operation, pressure relief valves reduce the pumping head to a fraction of its design value which in turn reduces the heating effect on the fuel proportionally. The pump head is just sufficient to overcome piping and other losses, and the heat to the chemical fuel is about 65,000 BTU per hour per engine. Any suitable arrangement may be used to dissipate this heat. One possible arrangement would be to utilize a fuel-to-air cooler with the fuel returned to the pump inlet.

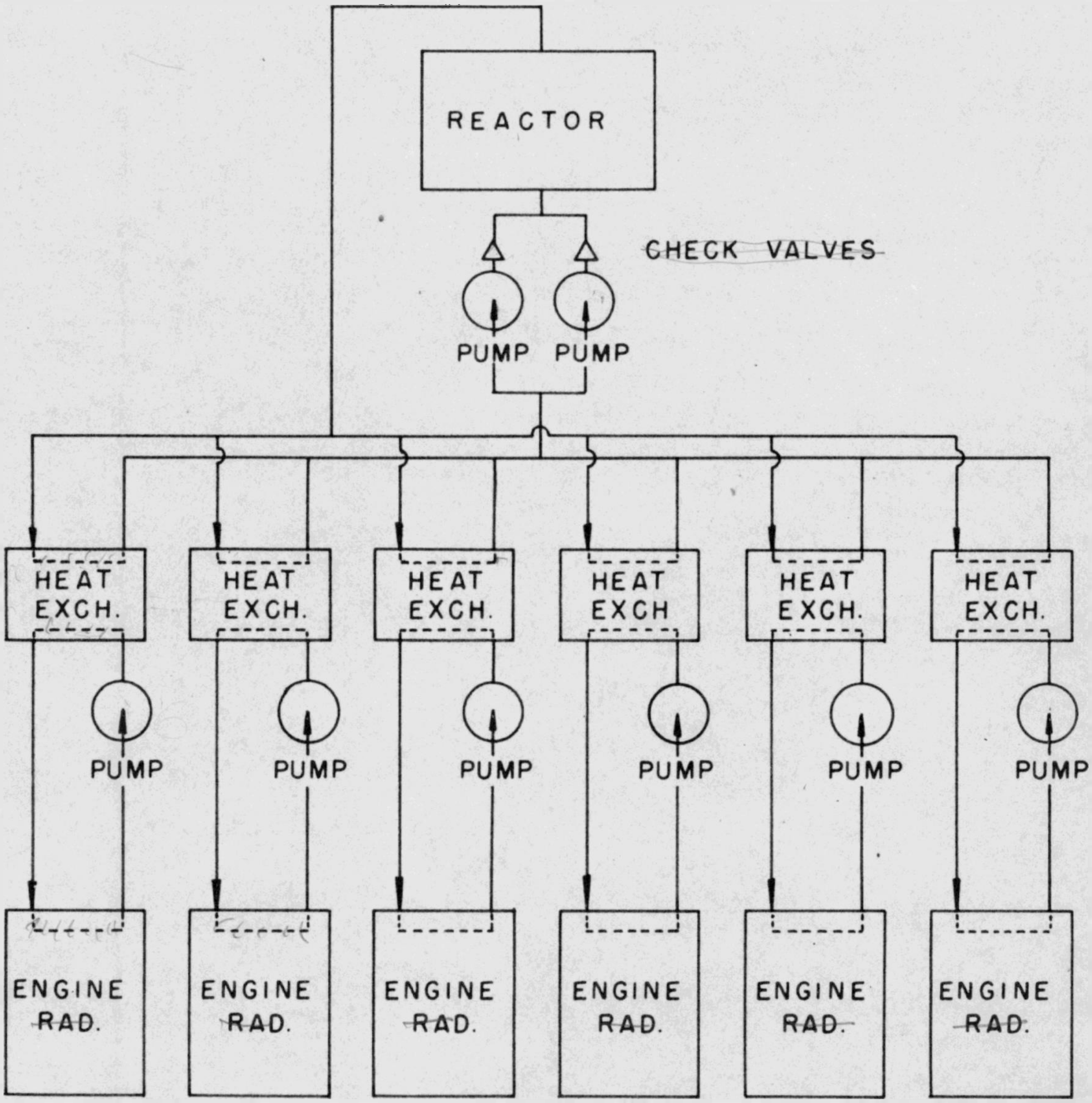
10. Control System Reliability and Duplication

The basic philosophy in the design of controls is to insure continued safe powerplant operation with a single control system component failure, and to provide wherever possible a fail safe arrangement. This concept has led to the design of the reactor drum controls as eight independent systems so arranged that the failure of any one (or even two or three in this case) to move as desired does not affect the operation of the others, and would not prevent continued operation for the remainder of a mission and normal shutdown thereafter. In many instances, however, the duplication of controls does not give this type of "multiengine" reliability, but may actually add to the chances for unsafe failures. In such cases there is no substitute for extreme reliability as a result of conservative design and many hours of development testing. It is anticipated that the necessary reliability will be achieved and that duplication of other powerplant controls is unnecessary and probably undesirable.

John W. Larson
John W. Larson

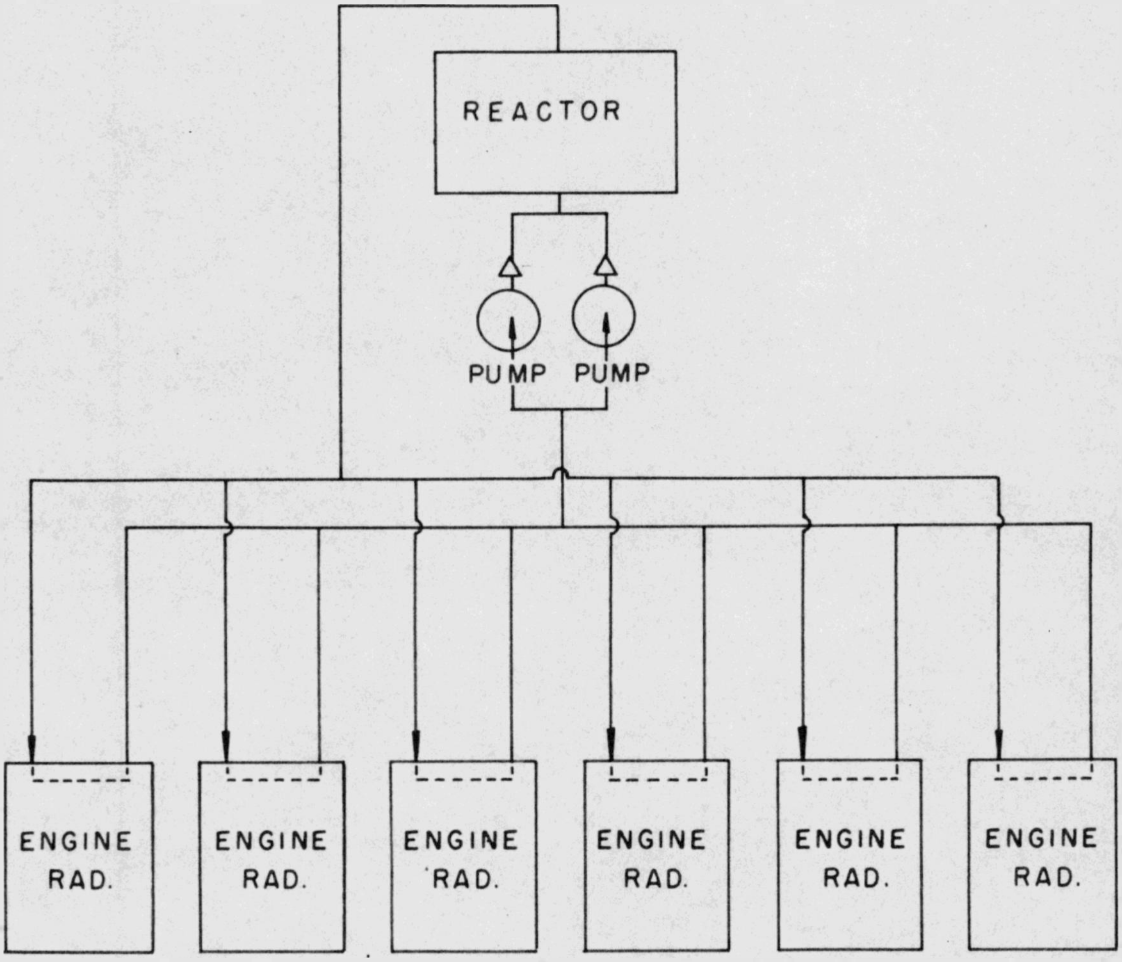
LIQUID METAL PIPING SCHEMATIC

SINGLE REACTOR, TWO LOOP POWERPLANT



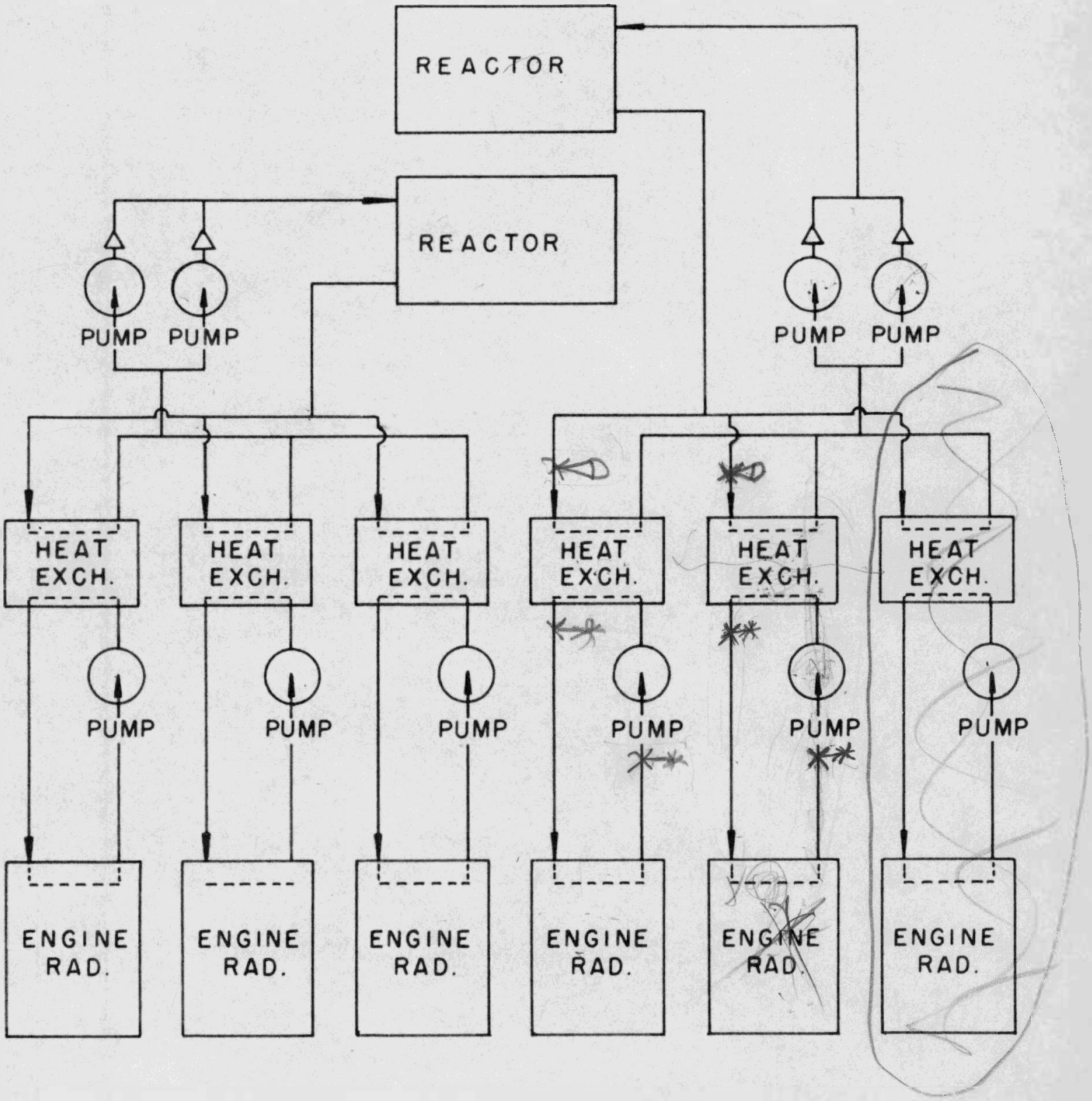
LIQUID METAL PIPING SCHEMATIC

SINGLE REACTOR, SINGLE LOOP POWERPLANT



LIQUID METAL PIPING SCHEMATIC

TWIN REACTOR, TWO LOOP POWERPLANT



WEIGHT ESTIMATE, POWERPLANT LESS REACTOR AND SHIELD

	1600 F NaK Radiator	1800 F NaK Radiator		2000 F Lithium Radiator
Number of engines	6	6		6
Turbojet engine weight				
Turbojet (exclusive of radiator)	5,100	5,100	6,289	5,100
Radiator	8,100	5,600	4,028	5,600
Total, lb/engine	13,200	10,700	10,317	10,700
Total, lb.	79,200	64,200	61,900	64,200
Primary liquid metal system				
Piping (wet, insulated)	3,500	3,500	3,900	9,500
Pumps and drives (wet)	2,100	2,100	2,600	2,000
Total, lb.	5,600	5,600	6,500	11,500
Secondary liquid metal system				
Piping (wet, insulated)	19,300	17,200	12,000	---
Pumps and drives (wet)	4,600	4,400	5,300	---
Total, lb.	23,900	21,600	17,300	---
Intermediate heat exchangers	14,000	13,000	5,200	---
Bleed air ducting	1,300	1,200	300	800
Bleed air radiators			1400	
Helium system	700	700		700
Subsystems			2100	
Shield coolant system	700	700		700
Inert atmos. container			600	
Control system	2,200	2,200	2500	1,900
Powerplant less reactor and shield, lb.	127,600 12?,200	109,200	97,800	79,800

Note:
1. Piping weights are based on 180 ft of lithium lines and 480 ft of NaK lines with an additional 15 percent allowance for expansion joints, couplings and pipe hangers, as required.
2. Weight of pumps and drives includes sump for liquid metal expansion and check valves as required.
3. For twin-reactor installations, add 800 lb to primary liquid metal system weight of pumps and drives.
4. Weight of bleed air ducting is based on 600 ft of line with an additional 15 percent allowance for expansion joints, couplings and pipe hangers as required.

8300
6
49800
45
94400

6000
5100
11,100

PIPING DATA

	1600 F NaK Radiator	1800 F NaK Radiator	2000 F Lithium Radiator
Piping for Lithium			
Outside diameter, in.	5.1	5.1	5.6
Wall thickness, in.	0.2	0.2	0.2
Weight (wet), lb/ft	16.8	16.8	17.1
Insulation weight, lb/ft	1.9	1.9	2.0
Insulation thickness, in.	2	2	2
Piping for NaK			
Outside diameter, in.	8.4	7.8	--
Wall thickness, in.	0.2	0.2	--
Weight (wet), lb/ft.	34.9	31.1	--
Insulation weight, lb/ft	2.7	2.6	--
Insulation thickness, in.	2	2	--
Bleed Air Duct for Pump-Turbine-Drives			
Outside diameter, in.	4.4	4.1	2.7
Wall Thickness, in.	0.04	0.04	0.04
Weight, lb/ft	1.9	1.8	1.2

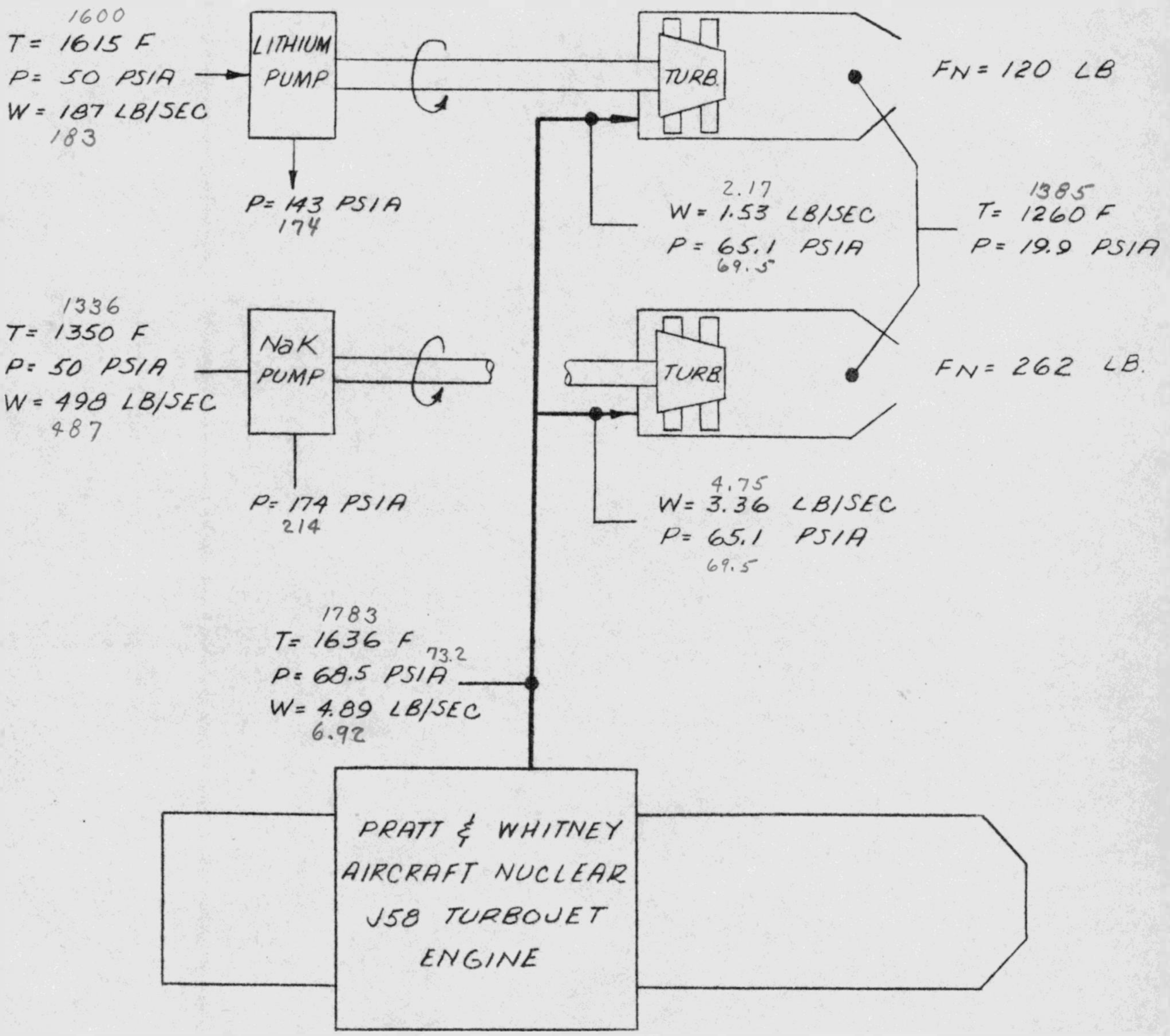
Note: 1. Outside pipe diameter does not include insulation thickness

2. Piping wet weight includes insulation weight

Fig 6

LIQUID METAL PUMP AND TURBINE DATA

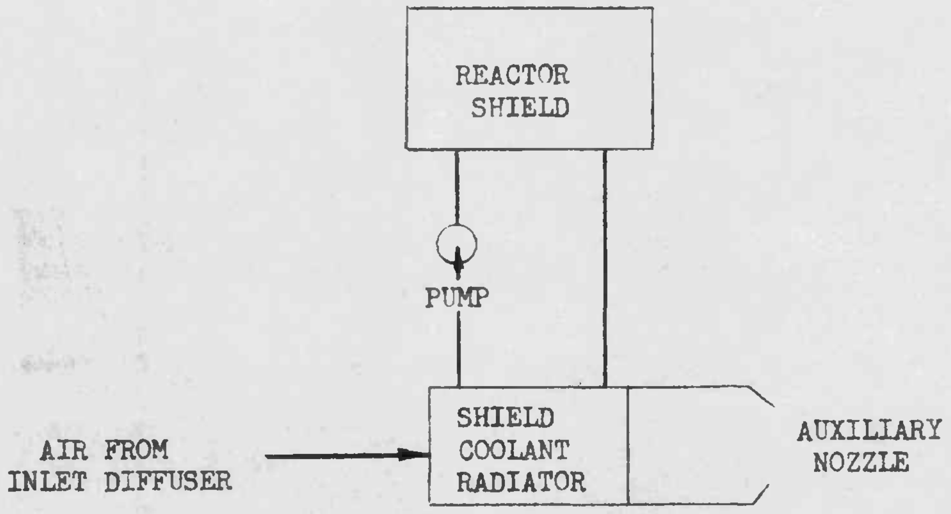
0.9 MACH NUMBER AND 25000 FT ALTITUDE



NOTE: ABOVE RESULTS ARE ON A PER ENGINE BASIS

SHIELD COOLING SYSTEM

Two Required Per Powerplant



WEIGHT AND SIZE

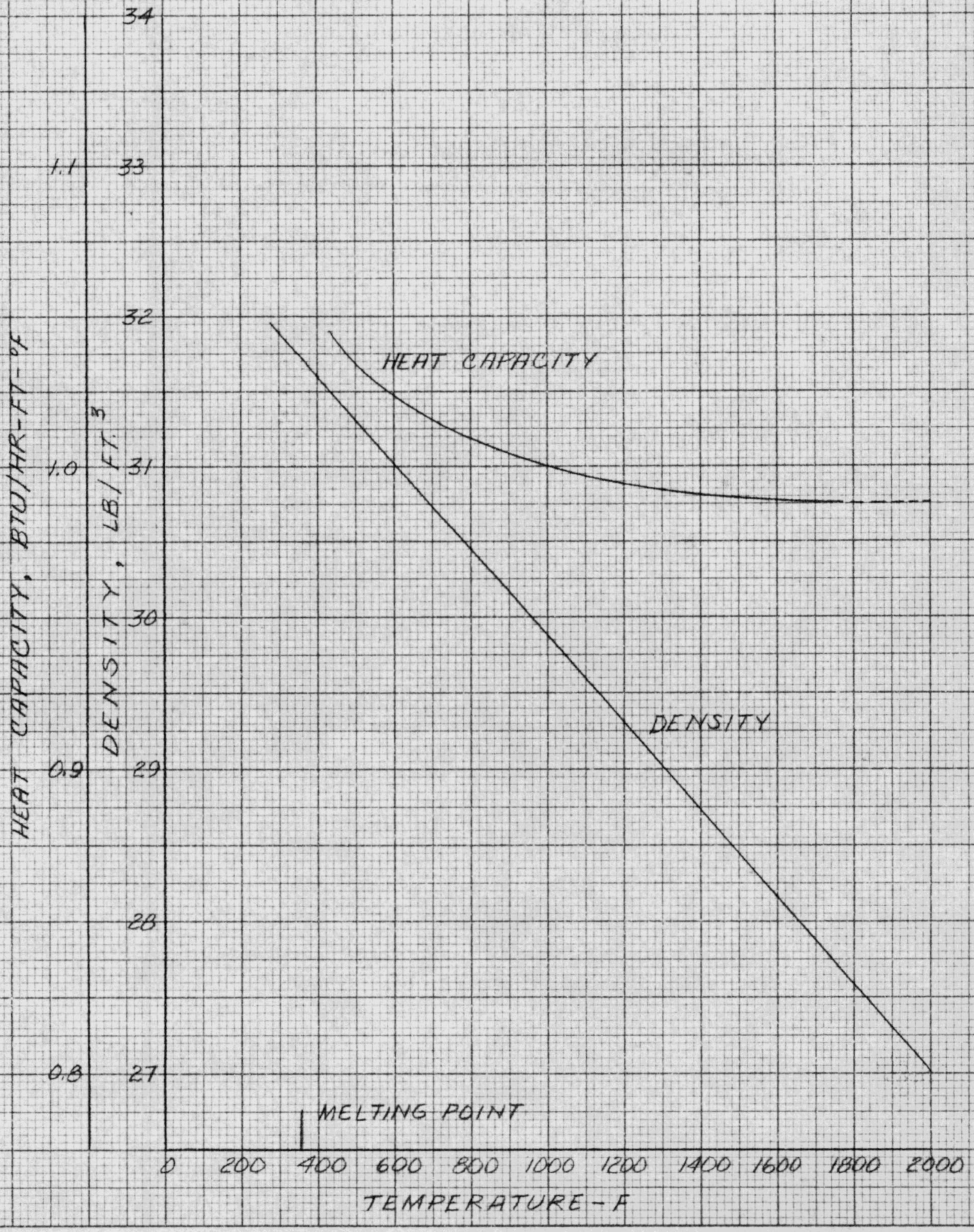
Air duct diameter	11 in.	Radiator weight	1660 lb.
Radiator face area	5.3 sq. ft.	Air duct weight	190 lb.
Radiator depth	2.5 ft.	Total	1850 lb.

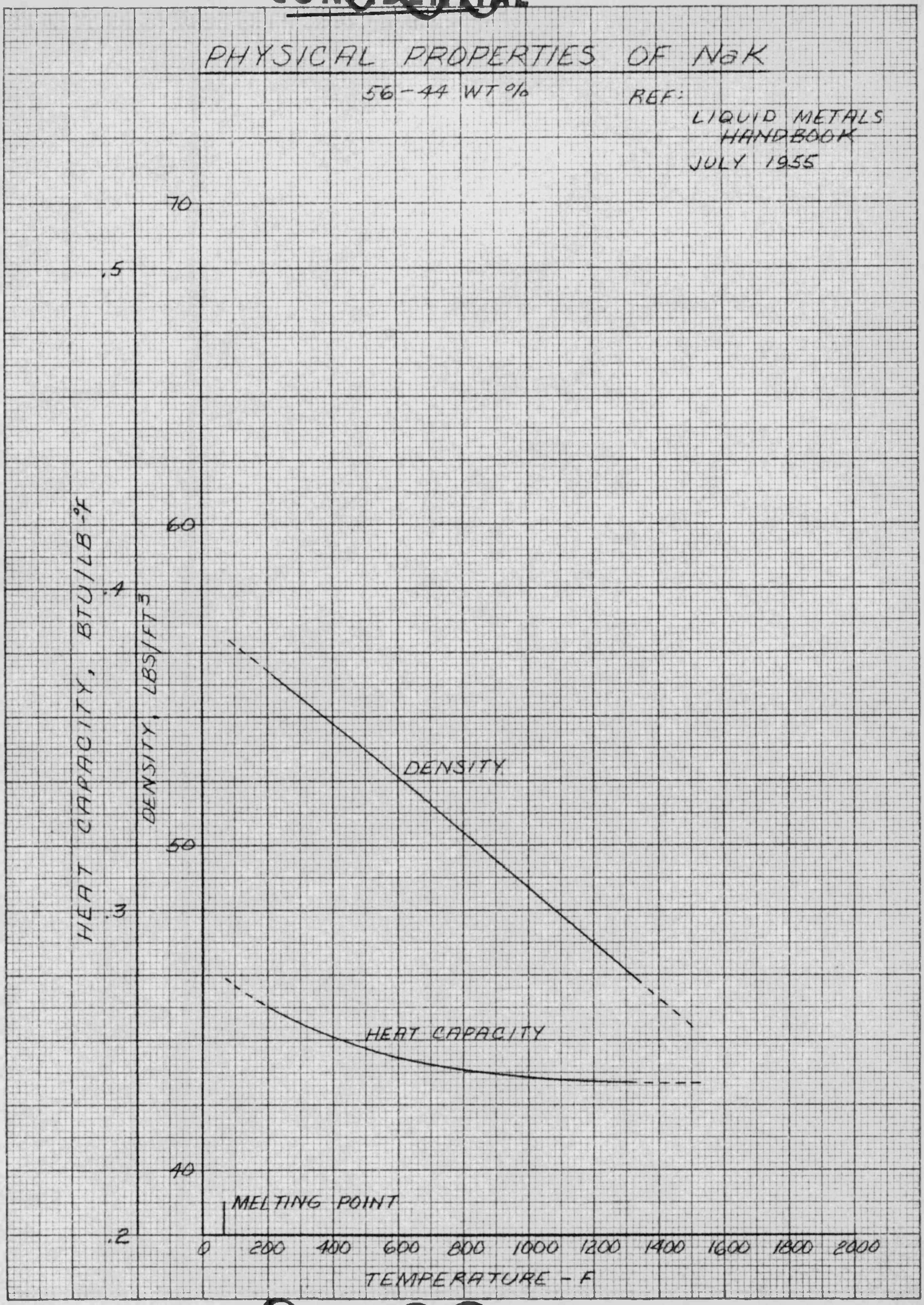
PERFORMANCE

Flight Mach number	0.9	3.0
Altitude, ft.	25,000	65,000
Heat output, KW	772	500
Shield coolant - Flow rate, lb/sec	2.04	7.5
Temperature in, F	550	750
Temperature out, F	400	650
Air - Flow rate, lb/sec	6.0	16.4
Nozzle Temperature, F	543	737
Nozzle pressure, PSIA	7.9	23.6
Net Thrust, lb	28	-30

PHYSICAL PROPERTIES OF LITHIUM

REF: FXM 2635
LIQUID METALS HANDBOOK
JUNE 1952





PHYSICAL PROPERTIES OF NaK

56 - 44 WT %

REF:
LIQUID METALS HANDBOOK
JULY 1955