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TORY II-C PERFORMANCE PARAMETERS

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by

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TORY II-C PERFORMANCE PARAMETERS

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Introduction:

The purpose of this paper is to present the theoretical performance parameters which have been established for TORY II-C. These parameters will be related to the performance of the missile and the components of which TORY II-C is composed.

We are considering a ramjet missile flying at an altitude of 1000 feet with the ambient temperature of 100°F. The design point of operation is defined as the point where flight control stability is achieved. This will be a function of the missile and engine performance parameters. Table I shows the flight and inlet parameters which are assumed to exist at the diffuser design point. The assumption is made that at Mach 2.8 we can obtain an overall pressure recovery of 80% by bleeding off 4% of the diffuser mass flow and that 80% of the momentum contained in this bleed-off can be recovered. The design value for the maximum fuel element wall temperature of 2500°F represents the present limit from the point of view of material technology.

Figure 1 shows the variation of net engine thrust with missile Mach number for ambient temperatures of 0°F, 60°F and 100°F. The omission of the customary drag lines reflects an uncertainty in the current knowledge of the final airframe configuration. The diffuser was designed for Mach 2.8. Above Mach 2.8 the diffuser performance drops and the flow rate becomes proportional to the Mach number. From Figure 1 we see that control stability is achieved in the region above Mach 2.8 where a decrease in flight Mach number causes the net engine thrust to increase and vice versa. If the missile Mach number should decrease to below Mach 2.8 it could possibly recover by diving and/or increasing power. Both of these methods however are rather dangerous modes of operation. The normal point of operation will therefore be at a missile Mach number which will be determined by the intersection of the drag line and the appropriate thrust curve to the right of Mach number 2.8. Adapted structural limits dictate that this point of operation does not exceed Mach 3.0 at an altitude of 1000 feet. A flight speed of Mach 3.0 is taken as the reactor's design operating point.

Table II is a compilation of pertinent Tory II-C parameters which have been calculated for the diffuser design point of Mach 2.8 and for the expected operating point of Mach 3.0. We see from this table that reactor power, and therefore net engine thrust, increases as the inlet total temperature decreases when the maximum wall temperature of the fuel elements is held constant. Since the inlet total temperature increases with flight Mach number and ambient temperature, an increase in either of these results in a decrease of net engine thrust, thereby contributing to the flight control stability mentioned previously.

The maximum material power density in the fuel elements of Tory II-C is less than that obtained in the fuel elements of Tory II-A and therefore presents no new problems in material technology.

Table III gives the flow distribution among the structural components of Tory II-C in the neighborhood of Mach 2.8.

Table IV gives the pertinent thermodynamic parameters which have been calculated for the structural components of Tory II-C for the flight condition of Mach 3.0. The temperatures in this table are the maximum for each component.

Since the net engine thrust is a function of the reactor gas power, it will be determined primarily by the performance of the fueled components or fuel elements. The performance optimization of the fuel elements is limited by the maximum material power density and temperature which may be achieved.

Since net engine thrust increases linearly with porosity, the porosity of the fuel elements was increased to a limit dictated primarily from neutronic requirements.

The maximum temperatures for the front support structure and the base plate are 1500°F and 2500°F respectively.

Figure 2 shows an optimization curve of net engine thrust versus fuel element flow passage diameter for a fixed fuel element porosity of .5298 and at the diffuser design point conditions.

As the flow passage diameter increases the number of fuel element flow passages must decrease for a fixed reactor size. Therefore, Figure 2 dictates the optimum flow passage diameter and the number of fuel element flow passages for a given size reactor. The initial optimization study was based on a ramjet engine composed of all fuel elements and indicated a flow passage diameter which is 4 mils smaller than the optimum suggested in Figure 2. The fuel element flow passage diameter has not been changed from the initially designed value of .23 inches since the indicated performance loss is less than .125% and it is doubtful that the calculational procedures are better than this.

Distribution:

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TABLE I.

Missile and Engine Parameters at the Mach 2.8 Diffuser Design Point.

a. Missile altitude = 1000 ft.

b. Ambient temperature = 100^{o}F.

c. Diffuser angle of attack = 0.0 deg.*

d. Diffuser overall pressure recovery = .80*

e. Diffuser bleed fraction = .04*

f. Bleed momentum recovery = .80*

g. Supersonic spillage = 0.0*

h. Exhaust nozzle velocity coefficient = .98**

i. Exhaust nozzle divergence coefficient = 1.00**

j. Maximum fuel element wall temperature = 2500^{o}F**

* These values are assumed to be constant below Mach 2.8.

** These values are assumed to be constant for all Mach numbers.

TABLE II

TORY II-C PERFORMANCE PARAMETERS

Flight Mach Number	2.8	3.0	2.8
Ambient Temperature (°F)	100	100	-50
Altitude (Ft)	1000	1000	1000
Reactor Inlet Total Temperature (°F)	946	1063	600
Reactor Inlet Total Pressure (psia)	322	349	325
Reactor Gas Power (Mw)	513	512	633
Reactor Flow Rate (pps)	1738	1864	1852
Net Base Thrust (pounds)	40000	33726	61300
Maximum Fuel Element Wall Temperature (°F)	2500	2500	2500
Maximum Fuel Element Thermal Stress (psi)	17,500	17,500	21,700
Maximum Fuel Element Material Power Density (MW/ft^3)	24.24	24.20	29.91
Normal Fuel Element Exit Mach No.	0.443	0.443	0.440
Reactor Total Pressure Drop (psi)	98	107	95

TABLE III.

FLOW DISTRIBUTION AMONG STRUCTURAL COMPONENTS OF TORY II-C

Fuel Elements	79.89%
Unfueled BeO	1.75%
Side Reflector Unfueled BeO	1.93%
Nickel Side Support Shims	1.09%
Tie Rods (Hastelloy)	4.27%
Control Tie Rods (Control rod fully withdrawn)	3.64%
Side Support Structure	7.43%

TABLE IV

THERMODYNAMIC PARAMETERS FOR THE STRUCTURAL COMPONENTS OF TORY II-C

Vehicle Mach. No.	= 3.0	Total Reactor Flow Rate	= 1864 pps
Vehicle Altitude	= 1000 ft.	Total Inlet Temperature	= 1063°F
Ambient Temp.	= 100°F	Total Inlet Pressure	= 348.6 Psia
Total Reactor Power	= 512 MW	Total Exit Pressure	= 251.6 Psia

COMPONENT	POWER (KW)	FLOW RATE (PPS)	PEAK WALL TEMP. (°F)	FLOW CHANNEL LENGTH* (IN.)	FLOW CHANNEL DIAMETER* (IN.)	POROSITY	NO. OF FLOW PASSAGES.	MATERIAL
Fuel Elements	23.73	.07143	2500	65.00	.2292	.5298	21,012	BeO Loaded with U_{235}
Insert Elements Adjacent to Tie Rods	3.886	.01632	1930	54.49	.1215	.1481	1,200	BeO
Side Reflector Elements	1.947	.007898	1927	65.00	.09402	.0888	3,876	BeO
Side Reflector Shims	3.432	.01974	1479	63.54	.1317	.1531	1,764	Ni
Tie Rods	19.02	.7478	1306	80.98	.5846	.7494	103	Hastelloy(R-235)
Control Rod (Fully Inserted)	90.66	1.71	1655	55.7			18	Hafnium
Control Rod Tie Rod	21.77		1430	80.98				Rene' 41
Side Support Springs		161.	1300					Rene' 41
Side Support Duct			1500					Hastelloy C

* Not Dimension

[redacted]

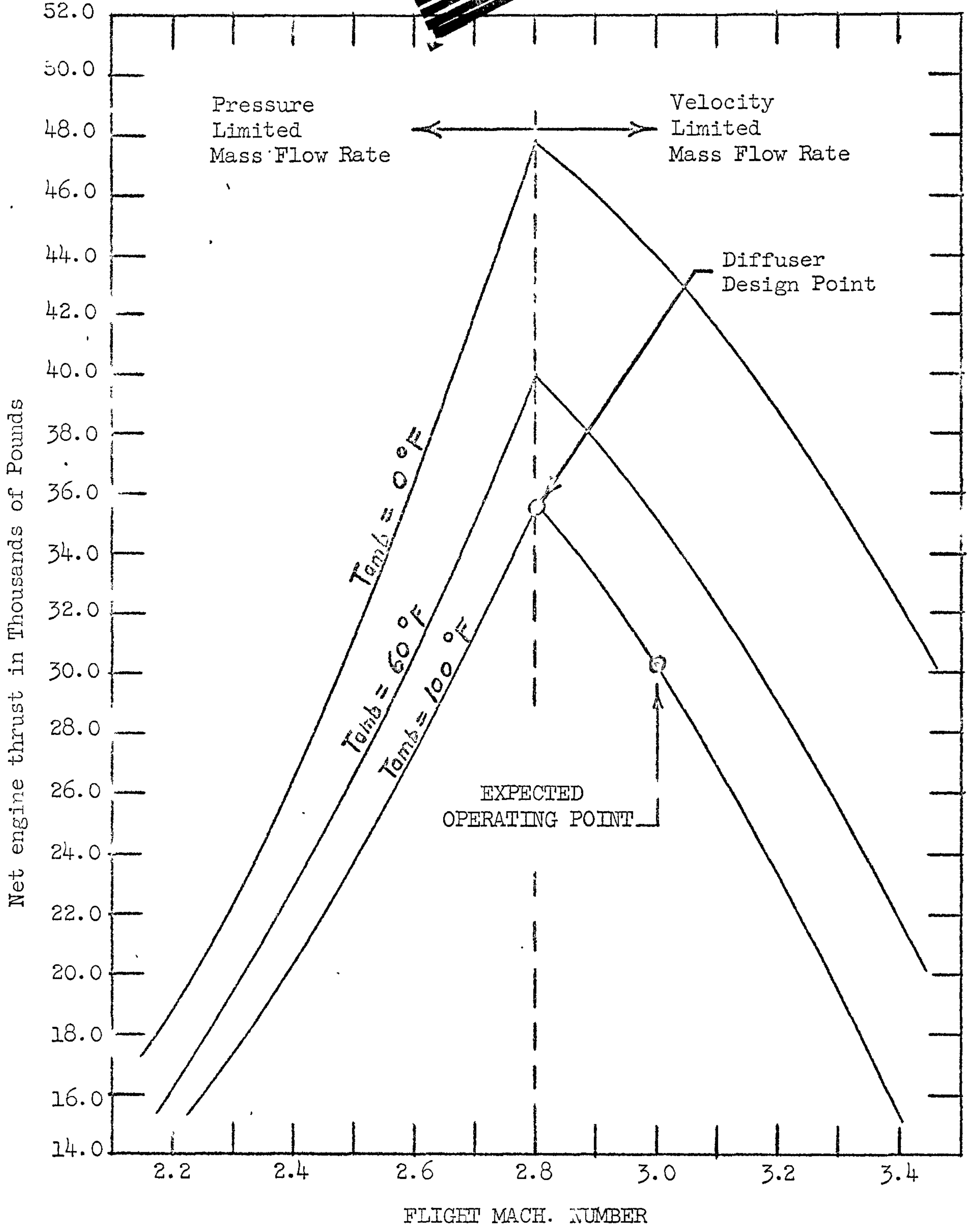

Fig. 1 Tory II-C net engine thrust vs. flight Mach. No., Maximum Fuel Element Wall Temperature = 2500°F, Altitude = 1000 ft.

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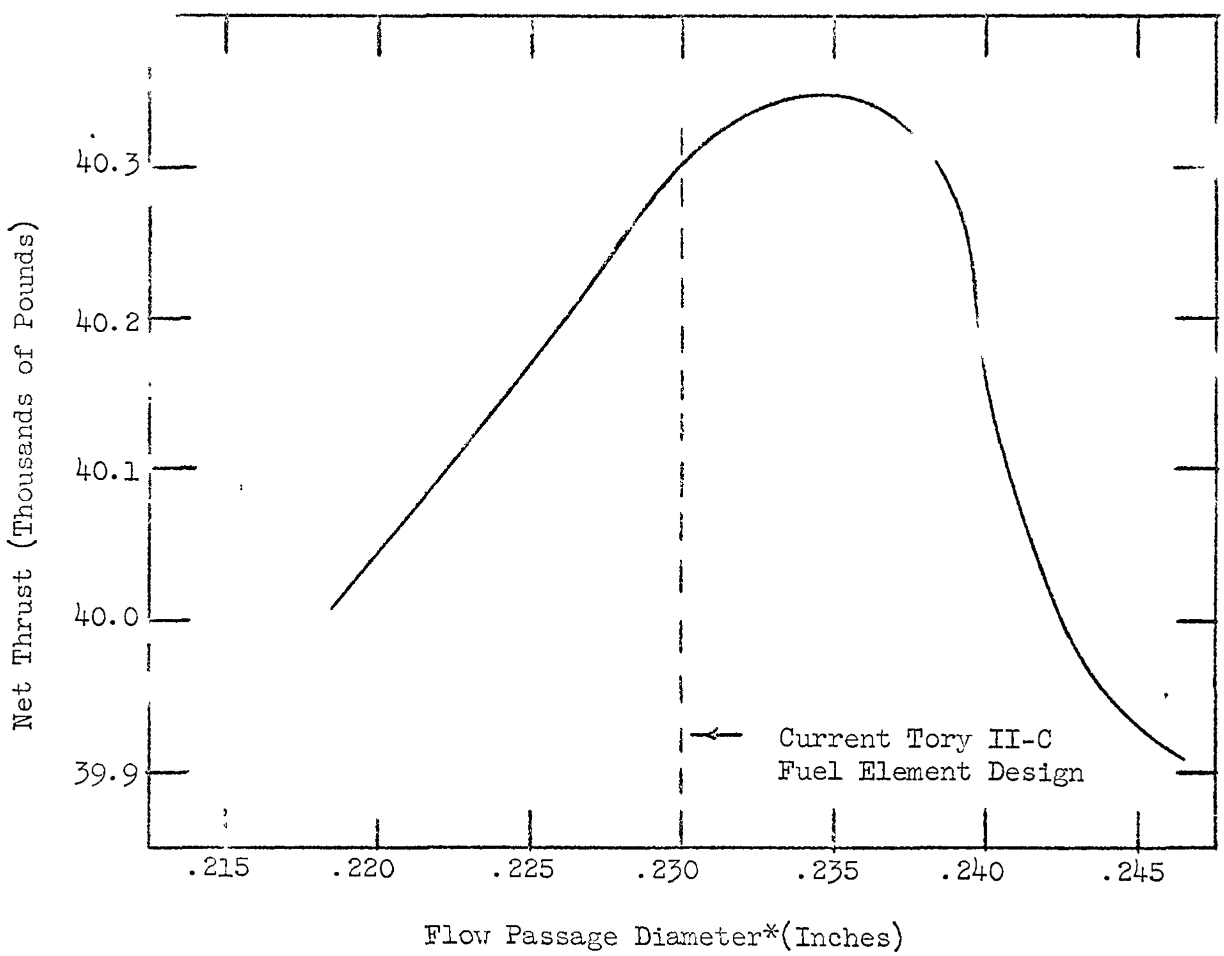

Fig. 2 Tory II-C Net Thrust vs. Fuel Element Flow Passage Diameter.

Diffuser Design Point. Variable Number of Flow Passages.

* Hot Dimension