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To: B. Mandell

From: L. A. Shurley

Subject: Alternate Nozzle Design Concepts

Distribution: J.J. Beereboom, I. L. Odgers

Enclosure: (1) Figures 1 thru 12 (Addressee Only)

Per your request, the following summary has been prepared of considerations given to the subject, and reflects the current position of this organization on the matter.

Three (3) basic nozzle configurations were considered for the purpose on reduction of nutron scatter. The principal mechanism of such reduction is reduction of the assemblies length. For conceptual statements please refer to appropriate pages of reproductions of material presented to the SNPO-C on May 24, 1968, a copy of which was provided to you.

One concept considered was a plug nozzle (isentropic spike), Figure (1). This configuration offers a maximum possiblity of length reduction, however, the area ratio is limited to 14:1 if the nozzle assembly envelope diameter were restricted to the existing pressure vessel diameter. The restriction could result in performance loss of approximately 40 seconds Isp compared with the 70:1 area ratio configuration.

Figure (2), depicts an approximate geometry of a 25:1 area ratio plug nozzle, assuming that the duct diameter rather than the Pressure Vessel diameter would be the limiting design parameter. This area ratio reduction represents approximately 20 seconds loss of performance. To what extent the increase in diameter of the assembly offsets the benefits derived from reduction of lengths, as far as radiation dose to the crew compartment is concerned has not been assessed. The plug nozzle was dropped from further consideration primarily because of the performance loss, plus severe heating problems and design problems in supporting and cooling of the plug. For effects of the equivalent throat diameter on heat transfer aspects, please consult Figures (11) and (12).

The second concept, Figure (4), multi-nozzles, which achieves reduced length through use of many small nozzles, represents minimum reduction of length compared with the other two considered.

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Unclassified
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This minimal shortening led us to believe that sufficent reduction or radiation scatter is not available to compensate for the increase design complexity and development difficulties expected with this approach. This concept, therefore, was also dropped from further consideration.

The forced deflection, Figure (6), otherwise known as expansion-deflection nozzle, (the third concept) offers the most promising alternate approach. It reduces the overall nozzle length by approximately 70 inches or about 40% of the conventional bell, with none or minimal loss of performance at equivalent area ratio.

The weight of this assembly was estimated to be approximately 200 lbs. less than the conventional Rao configuration.

Cooling and supporting the center plug does represent a difficult design task. The external shell, however, lends itself to cooling by conventional forced convection methods. The most important of all aspects would be the dissimilarities (ground vs. flight models) and resulting effects on ground test assemblies operation.

Duct limitations would dictate significant deviations from the flight configuration. Should there be no dissimilarities, acquisition of a suitable test facility, inclusive of stream generation system, would represent a considerable monetary investment.

A most profitable and practical approach to elimination of problems associated with a metallic skirt extension is development of this subassembly constructed from a nonmetallic material.

Our investigation indicates that graphitized carbon laminates or filaments show most promise. This approach would solve the problem on hand, without generating requirements for new or different test facility and is compatible with either hot bleed or a topping engine cycle.

It is, therefore, our recommendation that the alternate nozzle configuration be removed or, at least, suspended from further considerations. Unless otherwise directed, no further effort will be made in this direction.

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PLUG NOZZLE CONCEPT

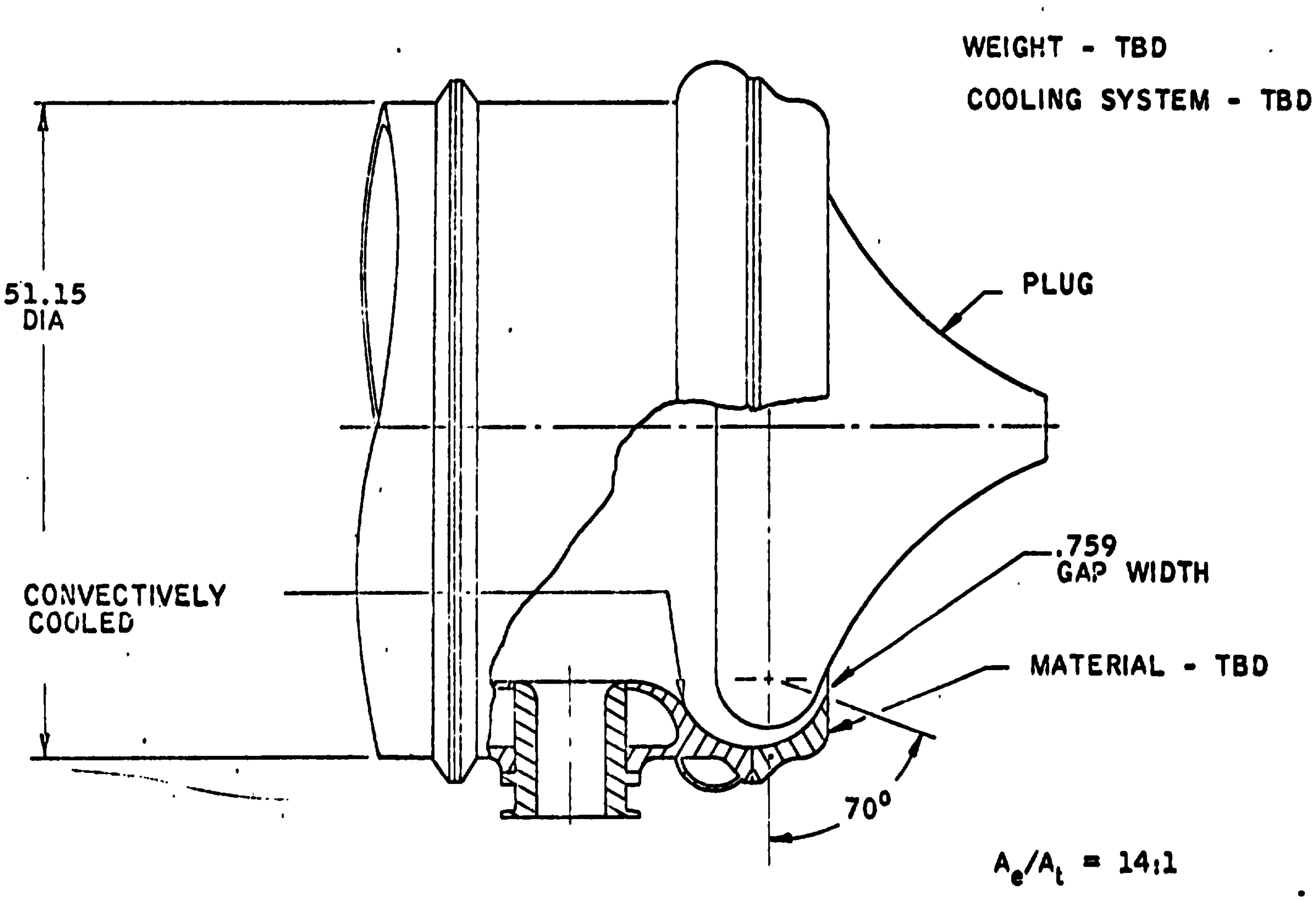

FIG 1

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PLUG NOZZLE CONCEPT

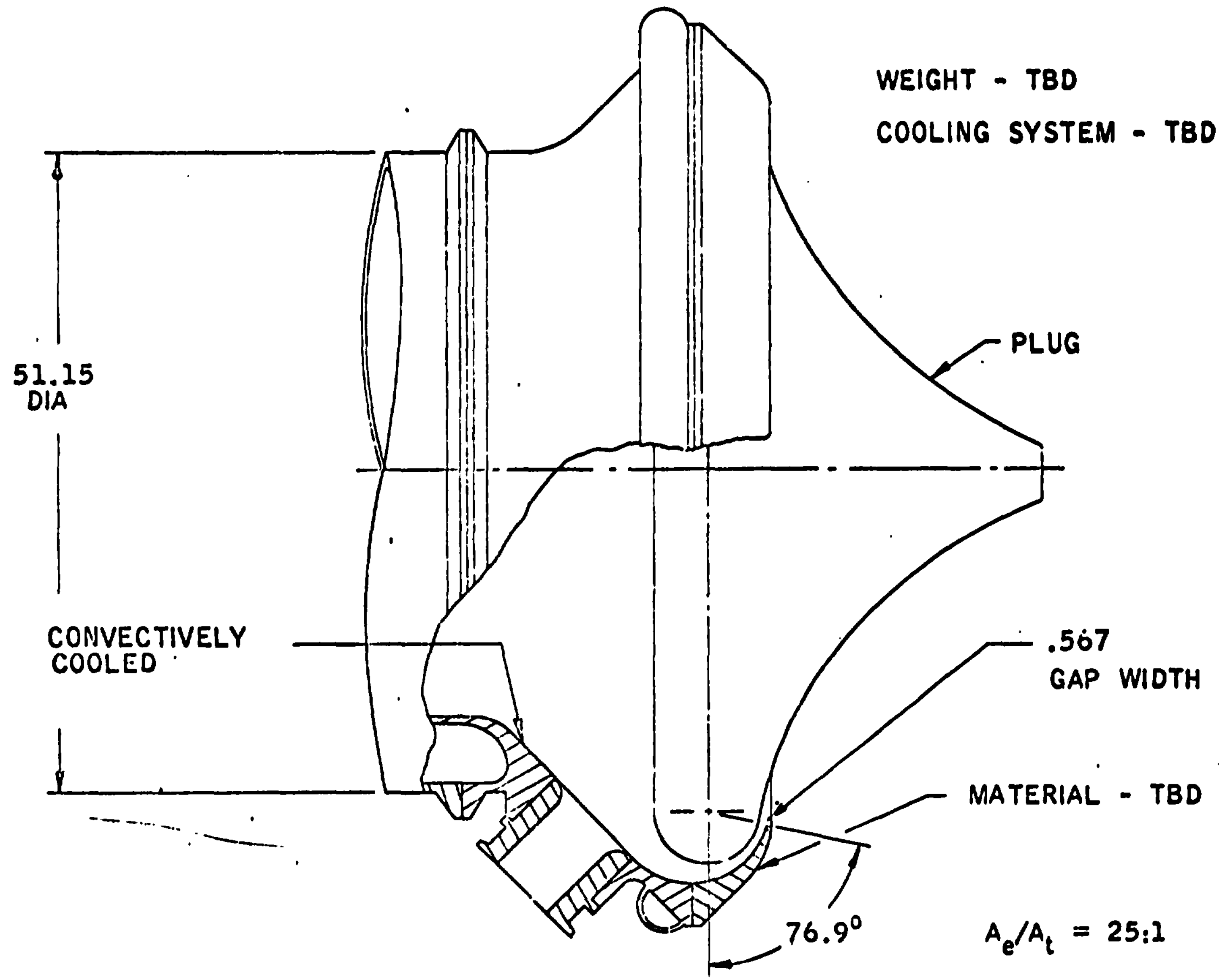

FIG. 2

PLUG NOZZLE

NOT PRACTICAL FOR THE FOLLOWING EASONS:

1. MAX A_e/A_t ATTAINABLE WITH EXISTING PV DIA WOULD BE 14:1, WHICH REPRESENT A PERFORMANCE LOSS OF APPROX. 40 SEC COMPARED TO PRESENT NOZZLE
2. INCREASE IN DIA OF NOZZLE TO ACHIEVE SAME PERFORMANCE WOULD INCREASE SHIELDING PROBLEM & WEIGHT
3. EQUIVALENT THROAT DIA WOULD DECREASE FROM 11.136 TO 1.52, THEREBY RESULTING IN SEVERE THROAT HEATING PROBLEMS, (COMPARABLE TO INCREASING P_c FROM 450 TO 760 PSIA)
4. DIFFICULTIES IN COOLING & SUPPORTING PLUG

FIG. 3

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NOZZLE LENGTH COMPARISON
MULTI VS. RAO CONTOUR

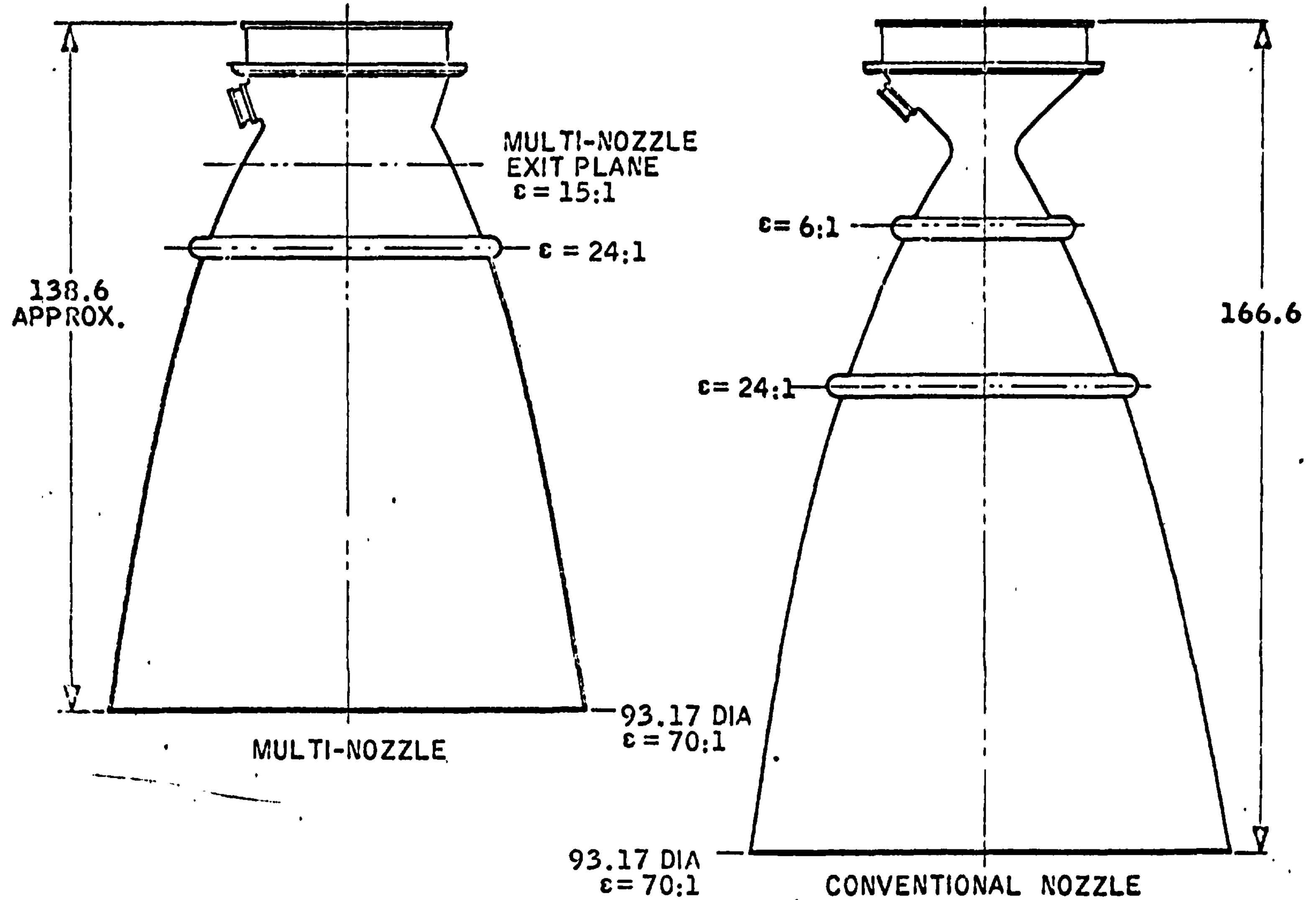

FIG. 4

MULTI NOZZLE

NOT RECOMMENDED FOR THE FOLLOWING REASONS:

1. RESULTS IN MINIMAL SHORTENING OF NOZZLE-SKIRT (APPROX 28.0 IN.)
2. DECREASE IN EQUIVALENT THROAT DIA WOULD CAUSE EXTREME HEATING PROBLEMS WHICH WOULD PROBABLY NECESSITATE USING A REFRACTORY THROAT LINER
3. COOLING THROAT INSERTS & SUPPORT PLATE WOULD BE A DIFFICULT DESIGN TASK
4. COST & TIME NECESSARY TO DEVELOP HARDWARE WOULD BE MORE THAN CONVENTIONAL NOZZLE
5. EFFECT ON ENGINE OPERATING CHARACTERISTICS COULD NOT BE EVALUATED WITHOUT EXTENSIVE ANALYTICAL & TESTING EFFORTS

FIG. 5

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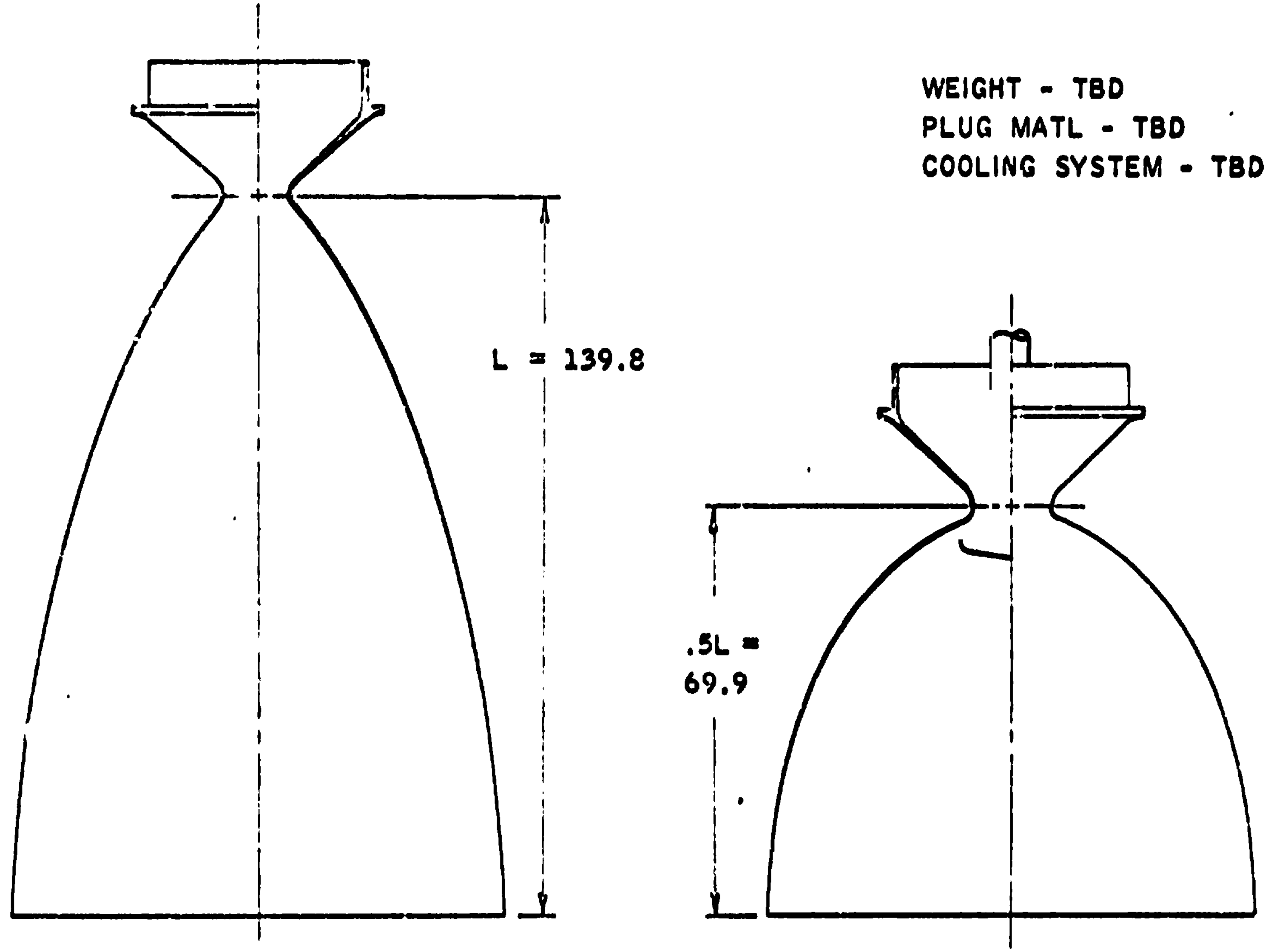
NOZZLE LENGTH COMPARISON
RAO VS. FORCED DEFLECTION



RAO CONTOUR
$\epsilon = 70$

FORCED DEFLECTION
$\epsilon = 70$

FIG. 6

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FORCED DEFLECTION NOZZLE
PLUG SUPPORT & COOLING CONCEPTS

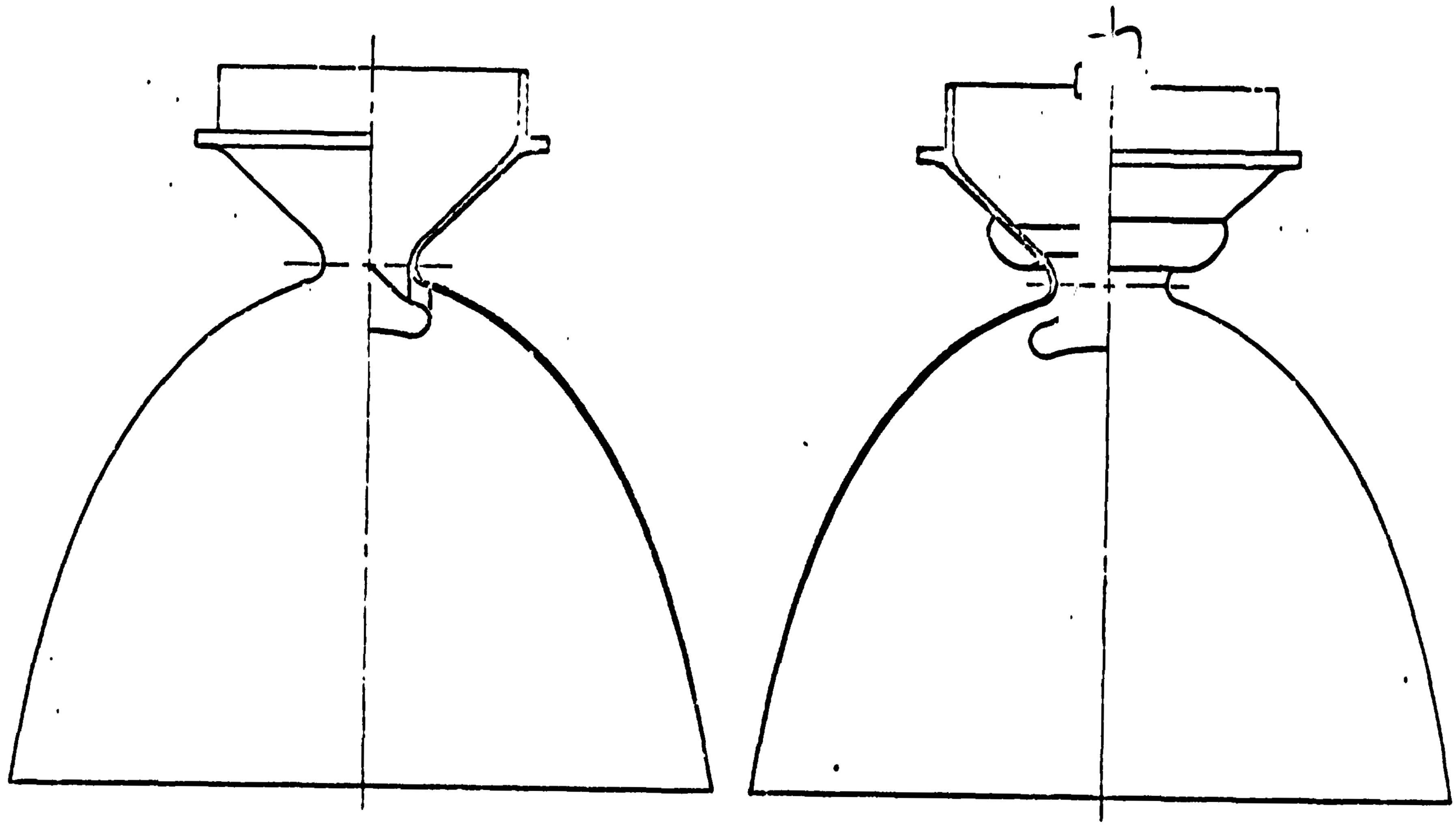

FIG. 7

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FORCED DEFLECTION NOZZLE

MOST PROMISING APPROACH FOR THE FOLLOWING REASONS:

1. MINIMAL OR NO LOSS IN PERFORMANCE COMPARED WITH CONVENTIONAL NOZZLE

2. REPRESENTS A LENGTH REDUCTION OF APPROX. 50% COMPARED TO A RAO NOZZLE-SKIRT ASSY

3. NOZZLE EXTERNAL SHELL, INCLUDING THROAT REGION CAN BE CONVECTIVELY COOLED, IF METHOD OF ROUTING COOLANT CAN BE DEVISED WITH MINIMUM PRESSURE DROP

4. WEIGHT IS UNKNOWN, BUT WEIGHT INCREASE WOULD BE LESS THAN MULTI OR PLUG NOZZLES

FIG. 8

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75K ENGINE OPTIMUM NOZZLE AREA RATIO

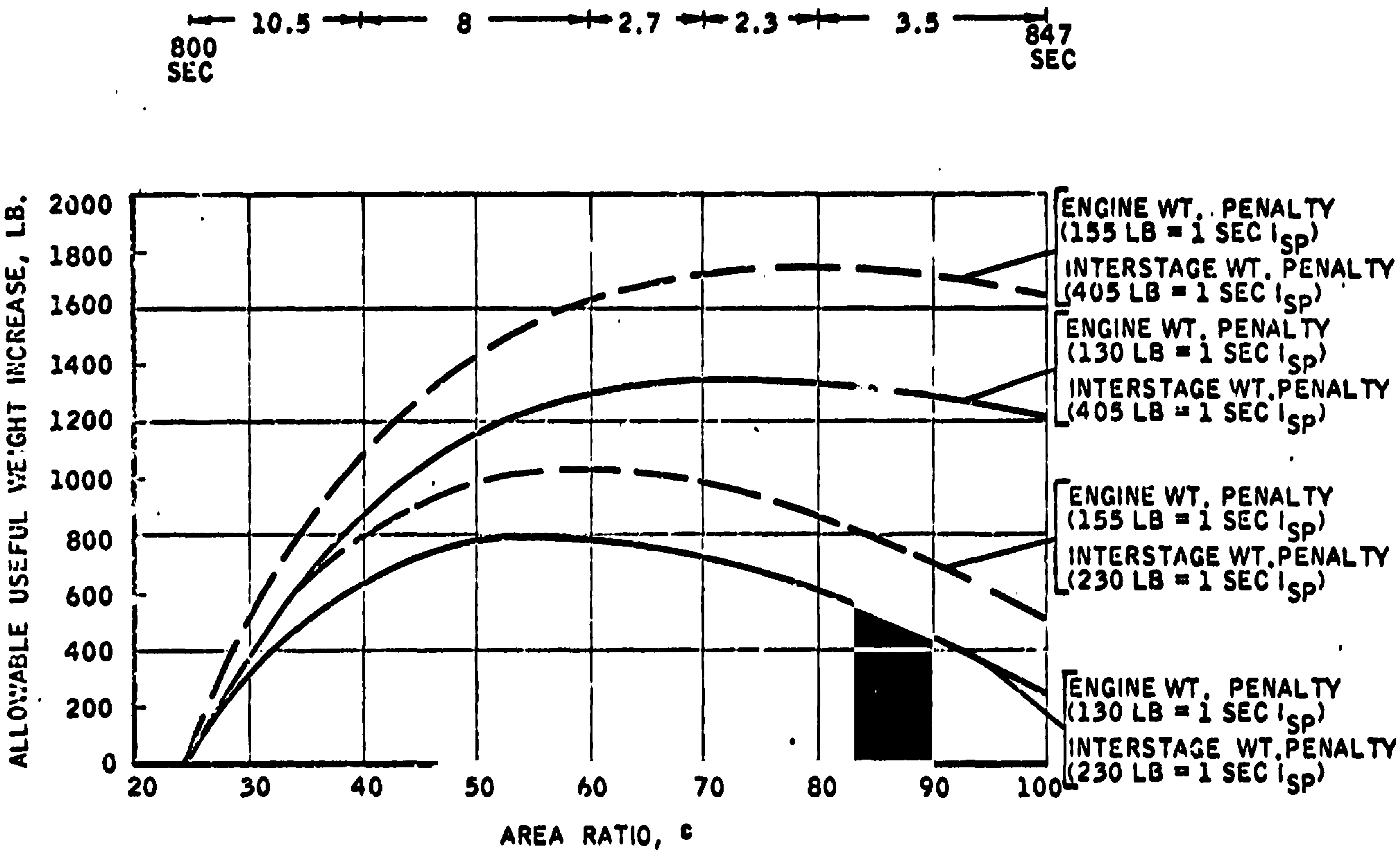

FIG.9

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RAO NOZZLE PERFORMANCE VS. AREA RATIO

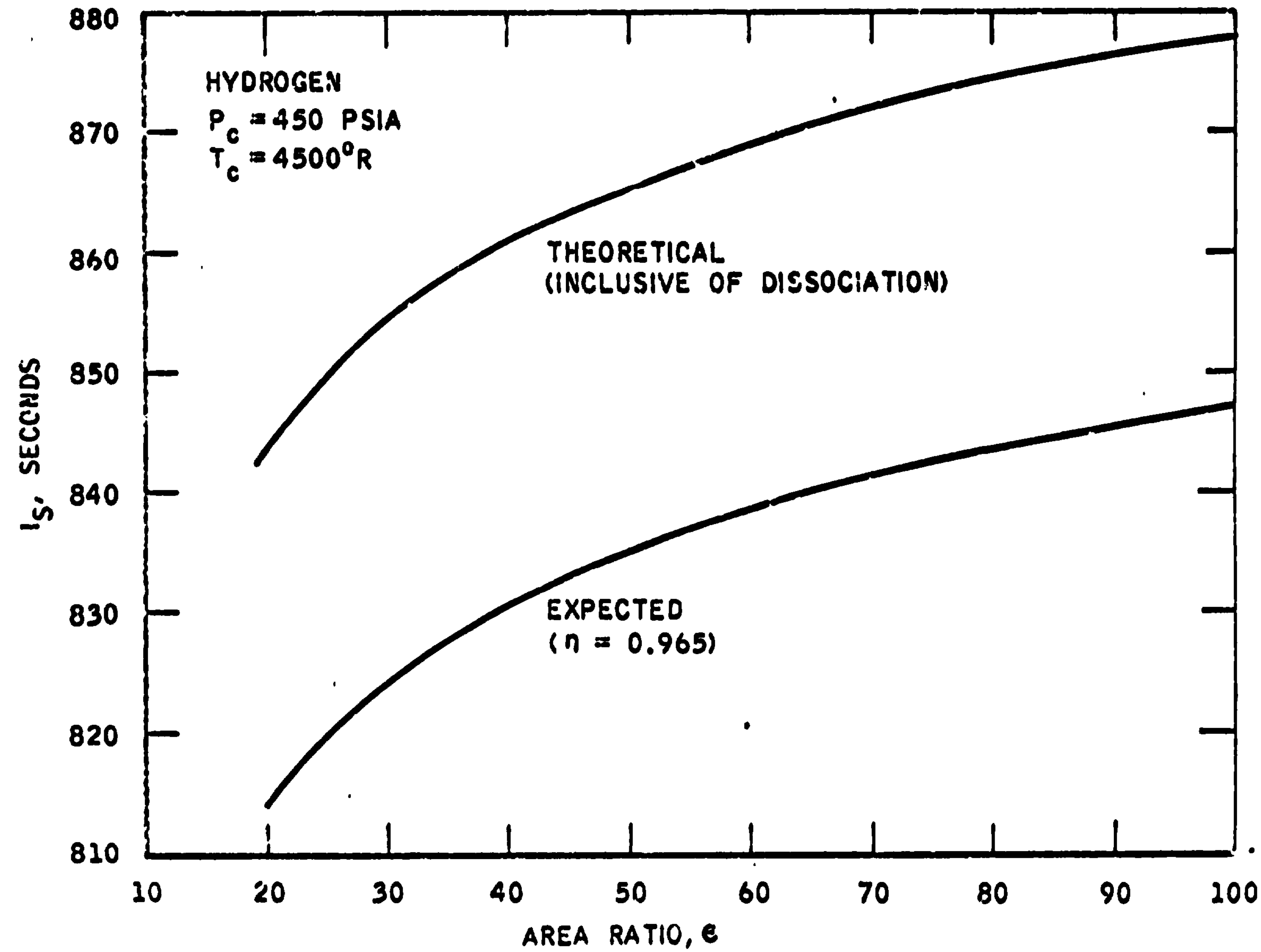

FIG. 1C

EQUIVALENT GAS SIDE DIAMETER-CHAMBER PRESSURE RELATIONSHIP

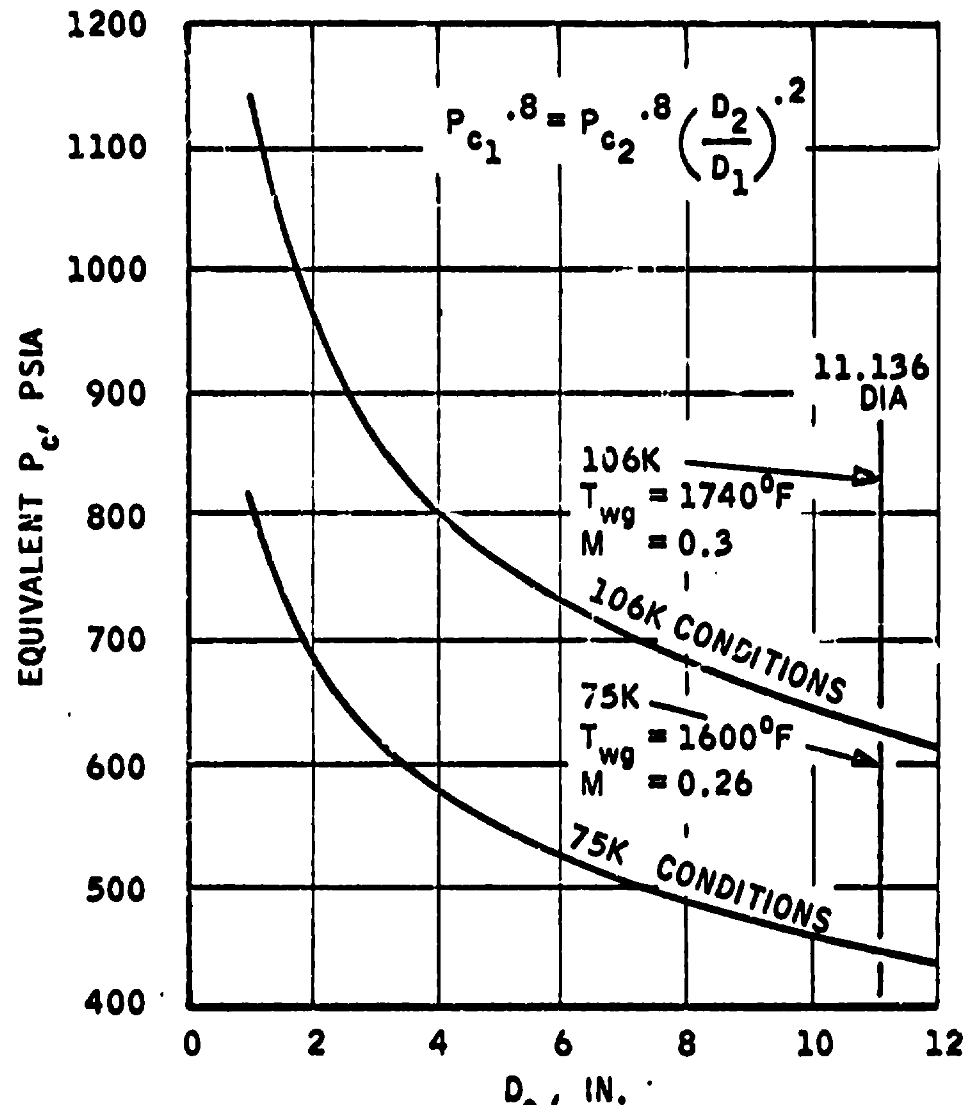

FIG. 11

EQUIVALENT GAS SIDE DIAMETER-CHAMBER PRESSURE RELATIONSHIP WITH CONSTANT T_{wg} MAX & MACH NO.

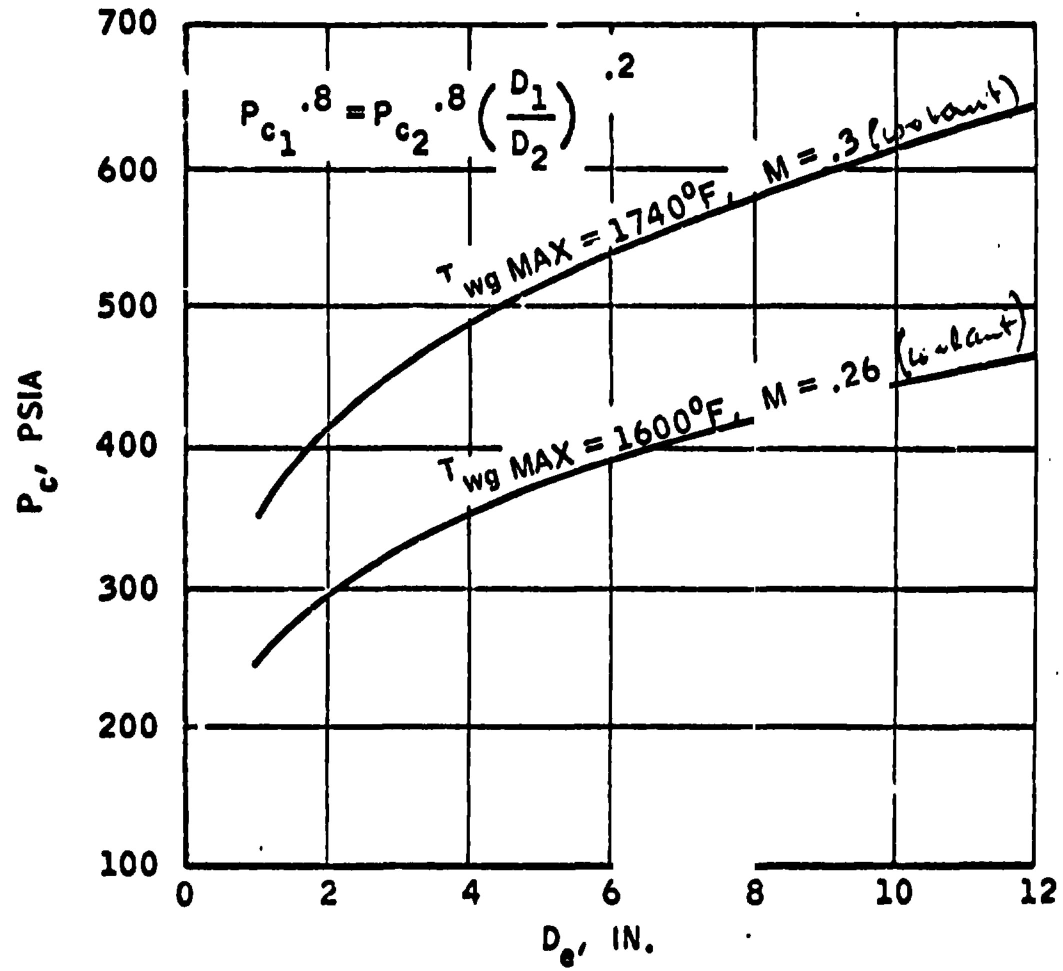

FIG. 12