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REON TECHNICAL MEMORANDUM

EFFECTS OF MODIFICATION TO DIFFUSER VANES
ON MARK III MOD 4
PUMPING PERFORMANCE

MASTER

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I INTRODUCTION

In order to provide a larger minimum flow area during bleed-in (chill-down) conditions, a modification to the Mark III Mod 4 housing diffuser vanes was considered. The modification would consist of removing material from the leading edge of the present diffuser vanes (as shown on Figure 1). The result would be increased flow area radially outward from the impeller prior to rotation. For good performance with the impeller rotating, the diffuser vanes are nearer to being tangent than radial. During the initial flow thru the pump (prior to drive pressure at the turbine) the pump impeller is not rotating. During this time, flow exits radially from the radial impeller vanes. Consequently, the incidence angle at the diffuser vanes is high, and the resulting vena contracta flow area is below that at any other point in the engine. Therefore, for a period of time, choked flow occurs at the pump diffuser vane entrances. A modification to eliminate this restriction was analyzed for the effects on the other pumping performance relations. The predicted effects of this modification on turbopump performance at nominal conditions are herein presented.

II CONCLUSIONS

1. The modification will not be detrimental to pumping performance at nominal conditions.
2. The modification will not noticeably affect pumping performance so long as the free vortex pattern of discharge occurs.
3. The stall limits of the Mark III Mod 4 turbopump with the modified diffuser vanes will occur at lower flows than that of the Mark III Mod 4 incorporating the standard diffuser vane configuration.
4. The modified diffuser has sufficient merit to be evaluated further during hydraulic tests.

III DISCUSSION

The modification to the Mark III Mod 4 housing diffuser vanes consisted of machining the vanes back from a base circle 12.68 inches in diameter to a base circle approximately 14.4 inches in diameter. The geometric areas for both the Mark III Mod 4 and modified Mark III Mod 4 diffuser flow passages were approximated from Figure 1, which is a scaled sketch of Drawing No. 284916. The areas calculated were the diffuser inlet and exit areas and the pump housing discharge area. These are tabulated below.

<u>Turbopump</u>	<u>Inlet Area</u>	<u>Exit Area</u>	<u>Discharge Area</u>
Mark III Mod 4	4.07 in ²	7.03 in ²	16.70 in ²
Modified Mark III Mod 4	4.38 in ²	7.57 in ²	16.70 in ²

Assuming that the fluid follows a free vortex pattern upon being discharged from the impeller, the velocity distribution through the diffuser will be affected only by the area increase normal to the flow path (the Mark III Mod 4 diffuser vanes were designed to guide the fluid in a free vortex pattern of flow).

Assuming a boundary layer of 5% at inlet and 10% at exit, the velocities for the two configurations, at nominal conditions, may be calculated. The respective velocities were calculated to be:

	<u>Mark III Mod 4</u>	<u>Modified Mark III Mod 4</u>
Inlet	650 ft/sec	607 ft/sec
Exit	398 ft/sec	370 ft/sec
Discharge	143 ft/sec	143 ft/sec

Since an error of $\pm 10\%$ may enter into these calculations depending on various factors such as frictional losses and boundary layer thickness, the differences in velocity, and, therefore, performance of the two diffusers may be assumed to

negligible. It is to be noted that these calculations are applicable only when a free vortex pattern of flow exists.

In order to determine the effect of the diffuser vane modification on stall limits of the Mark III Mod 4 turbopump, it was assumed that stall would occur at the same incidence to vane angle ratio (i/β_v) as with the previous vane configuration. The i/β_v values for stall for the Mark III Mod 4 turbopump were calculated from Figure 2. Taking the mean camber line of the modified vane with respect to a line tangent to the base circle as the vane angle (Figure 1), and the incidence to vane angle ratio being given, the flow rate at which stall would occur could be predicted. The predicted stall limits with the modified diffuser vane are shown on Figure 3. As can be seen, the modified diffuser vanes allow the turbopump to operate at much lower flows.

Figure 1

FIGURE 1
DIFFUSER VANES

NERVA
MARK III MOD 4 TURBOPUMP
LH₂ PUMPING PERFORMANCE
STALL LIMITS

Figure 2
1.2.3-65-0-032

NERVA LH₂ PUMPING PERFORMANCE STALL LIMITS MARK III MOD 4 TURBOPUMP

FIGURE 3
1.2.3-65-C-103

2-2-65 TJS

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CALCULATIONS

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Velocity through Beveridge
and Mark III Mod 3 diffusers

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Since the fluid is assumed to continue its forced vortex path of flow upon discharge from the impeller, the difference in velocity through the Mark III Mod 4 and Beveridge diffuser designs should not be significant at nominal operating conditions.

The differences in velocity between the two designs will be due to differences in diffuser areas.

These were approximated by scaling from Dwg #284916. For the Mark III Mod 4:

$$\begin{array}{r} \text{Inlet Area: } 8.14 \quad 0.83 \\ - 6.34 \quad 0.55 \quad 0.28 \\ \hline 1.80 \quad 0.28 \quad \frac{0.28}{2} = 0.14 \end{array}$$

$$\tan \psi = \frac{0.14}{1.80}, \quad \psi = 4.46^\circ$$

Normal to Flow Path

$$\begin{array}{r} 7.27 \\ - 6.44 \\ \hline 0.83 \end{array}$$

From similar Δ 's

$$\frac{0.83}{1.80} = \frac{h}{0.14} \quad h = 0.0645$$

$$a = 0.55 + 2(0.0645) = 0.679''$$

Area of one passage way, A_p

$$A_p = 0.83 \left(\frac{1}{2} \right) (0.679 + 0.55) = 0.509 \text{ in}^2$$

$$A_T = 8 A_p = 4.07 \text{ in}^2$$

Assume 5% boundary layer

$$A_T' = 3.86 \text{ in}^2 = 0.0269 \text{ ft}^2$$

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Exit Area:

$$\begin{array}{r} 6.84 \\ + 1.11 \\ \hline 6.95 \end{array} \quad \begin{array}{r} 6.95 \\ - 6.34 \\ \hline 0.61 \end{array}$$

From similar triangles:

$$\frac{0.61}{1.80} = \frac{h_2}{0.14}, \quad h_2 = 0.0475$$

$$a_2 = 0.55 + 2(0.0475) = 0.645''$$

$$\begin{array}{r} 8.14 \\ - 6.95 \\ \hline 1.19 \end{array}$$

$$A_{p_2} = 1.19 \left(\frac{1}{2} \right) (0.645 + 0.83) = 0.878 \text{ in}^2$$

$$A_{T_2} = 8(0.878) = 7.03 \text{ in}^2 = 0.0488 \text{ ft}^2$$

Assume 10% boundary layer

$$A'_{T_2} = 0.0440 \text{ ft}^2$$

For the Beveridge diffuser, Inlet Area

$$\begin{array}{r} 8.14 \\ 6.84 \\ \hline 1.80 \end{array} \quad \begin{array}{r} 0.83 \\ 0.55 \\ \hline 0.28 \end{array} \quad \frac{0.28}{2} = 0.14$$

$$\begin{array}{r} 7.27 \\ - 6.39 \\ \hline 0.88 \end{array}$$

From similar Δ 's

$$\frac{0.93}{1.80} = \frac{h_1}{0.14}, \quad h_1 = 0.0725$$

$$a = 0.55 + 2(0.0725) = 0.695''$$

$$A_{p_1} = 0.88 \left(\frac{1}{2} \right) (0.695 + 0.55) = 0.547 \text{ in}^2$$

$$A_{T_1} = 4.38 \text{ in}^2 = 0.0304 \text{ ft}^2$$

Assuming 5% boundary layer,

$$A'_{T_1} = 0.0289 \text{ ft}^2$$

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Exit Area

$$\frac{8.14}{-6.84} \\ 1.30$$

$$\frac{6.84}{-6.34} \\ 0.50$$

$$\frac{0.50}{1.80} = \frac{h_2}{0.14}$$

$$h_2 = 0.0388$$

$$a_2 = 0.55 + 2(0.0388) = 0.6276''$$

$$A_{P_2} = 1.30 \left(\frac{1}{2} \right) (0.6276 + 0.83) = 0.946 \text{ in}^2$$

$$A_{T_2} = 8(0.946) = 7.57 \text{ in}^2 = 0.0526 \text{ ft}^2$$

Assume 10% boundary layer

$$A'_{T_2} = 0.0474 \text{ ft}^2$$

The velocities for nominal X-E conditions are then:

Diffuser	Mark III Mod 3	Beveridge
Inlet	650 ft/sec	607 ft/sec
Exit	398 ft/sec	370 ft/sec

Housing

Discharge Area (4.62" dia.) = 0.116 ft² assume 5% boundary

Discharge velocity = 143 ft/sec

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Modified Diffuser
Stall Limit

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From Figure 1

$$\beta_V = 11.5^\circ \text{ (mean camber line)}$$

Assuming a free vortex, $rv = \text{constant}$.

The peripheral velocity at nominal flow and 20,000 rpm at the impeller tip is:

$$C_u = \frac{N d_t}{229} = 1070 \frac{\text{ft}}{\text{sec}}$$

The slip factor is:

$$\eta = 1 - \frac{0.63\pi}{n} = 0.959$$

and the velocity into the diffuser is:

$$C_u' = 0.959 C_u = 1025 \frac{\text{ft}}{\text{sec}}$$

From the free vortex relationship, the peripheral component of velocity at the modified diffuser is:

$$C_u'' = \frac{6.34}{7.27} \times 1025 = 895 \frac{\text{ft}}{\text{sec}}$$

The area normal to the flow path at the modified diffuser inlet is:

$$A_p = 1.80 \left(\frac{1}{2}\right) (0.55 + 0.83) = 1.24 \text{ in}^2$$

$$A_T = 8 A_p = 9.9 \text{ in}^2 = 0.0688 \text{ ft}^2$$

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From 1.2.3-65-C-032,

 $\frac{Q}{N}$ @ stall @ 20,000 RPM = 0.22 for

$$\frac{H_{SV}}{N^2} = 2.0 \times 10^{-6} \frac{\text{ft}}{\text{RPM}^2} \quad \text{— Data for Mod 3 pump housing}$$

$$\frac{i}{\beta_V} = 1 - \frac{\beta_F}{\beta_V}$$

$$\beta_F = \tan^{-1} \frac{c_m}{u} = \tan^{-1} \frac{91.5}{1025} = 5.13^\circ$$

$$\beta_V = 9.25^\circ$$

$$\frac{i}{\beta_V} = 1 - \frac{5.13}{9.25} = .445$$

Assuming that stall occurs at the same i/β_V ,

$$\frac{\beta_F}{\beta_V} = 0.555 \text{ for the modified diffuser, and}$$

$$\beta_F = 0.555(9.25) = 5.13^\circ$$

$$\tan^{-1} \beta_F = 0.112$$

$$\frac{c_m}{c_u} = 0.112, \quad c_m = 895(0.112) = 100 \frac{\text{ft}}{\text{sec}}$$

$$Q = AV = 0.0698(100) = 6.98 \frac{\text{ft}^3}{\text{sec}} = 3090 \text{ gpm}$$

$$\frac{Q}{N_{\text{stall}}} = 0.155 \frac{\text{gal}}{\text{rev}}$$

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$\frac{H_{SV}}{N^2}$	N	$\frac{Q_{stall}}{N_{Mod3}}$	Q_{Mod3}	$C_{L''}$	Cm	$\frac{Q_{stall}}{N_{modified}}$
2.0×10^{-6}	20K	.22	4400	895	100	0.155
..	14K	.202	2830	625	63.9	0.141
..	8K	.167	1340	358	30.3	0.116
1.0×10^{-6}	20K	.256	5120	895	116.5	0.180
..	14K	.237	3320	625	75	0.166
..	8K	.199	1590	358	36.2	0.139
0.5×10^{-6}	20K	.274	5480	895	123.5	0.191
..	14K	.252	3530	625	79.4	0.175
..	8K	.214	1710	358	38.7	0.149
0.15×10^{-6}	20K	.293	5860	895	132.5	0.205
..	14K	.265	3710	625	83.6	0.185
..	8K	.226	1810	358	41.2	0.159