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COMPUTATIONAL FLUID DYNAMICS (CFD) IN THE DESIGN OF A WATER-JET-DRIVE SYSTEM

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SUMMARY

NASA/Marshall Space Flight Center (MSFC) has an ongoing effort to transfer to industry the technologies developed at MSFC for rocket propulsion systems. The Technology Utilization (TU) Office at MSFC promotes these efforts and accepts requests for assistance from industry. One such solicitation involves a request from North American Marine Jet, Inc. (NAMJ) for assistance in the design of a water-jet-drive system to fill a gap in NAMJ's product line. NAMJ provided MSFC with a baseline axial flow impeller design as well as the relevant working parameters (rpm, flow rate, etc.). This baseline design was analyzed using CFD, and significant deficiencies identified. Four additional analyses were performed involving MSFC changes to the geometric and operational parameters of the baseline case. Subsequently, the impeller was redesigned by NAMJ and analyzed by MSFC. This new configuration performs significantly better than the baseline design. Similar cooperative activities are planned for the design of the jet-drive inlet.

DISCUSSION

NAMJ is a small company in Arkansas which manufactures water-jet-drives. NAMJ's product line has a gap in the 350 to 500 hp range. They identified a potential market demand for a drive system in that range and solicited help from NASA/MSFC's TU Office. The TU Office coordinates requests made by industry for NASA support. The goal of these activities is to make American industry more competitive by transferring NASA technology and providing industry with access to NASA expertise. NAMJ requested NASA support in the analysis of their proposed 350-500 hp system as well as information on pump testing and testing instrumentation. MSFC agreed to perform the requested analyses because it would benefit U.S. industry. The large customer identified by NAMJ was currently using a foreign manufactured jet-drive-system. Also, in general, the entire marine jet-drive industry had not made use of CFD to improve their designs. MSFC has demonstrated and promoted the value of using CFD in the design process [1, 2, and 3]. A final reason for performing this study is that it provided MSFC with the opportunity to identify and remedy shortcomings in MSFC's analysis procedure and the opportunity to expand MSFC's pump analysis experience base.

NAMJ provided MSFC with a baseline design (figure 1) along with the operating characteristics (table 1). This design was a scaled version of a 30 year old design. A significant effort was required at MSFC to generate a gridi of the baseline design because the geometry definition had to be extracted from difficult to read drawings. Furthermore, the blade profile was specified only for the pressure surface. With the available information, MSFC was able to create a camber line definition and a thickness distribution at two radial stations. Defining the camber line and thickness distribution was necessary to facilitate the planned geometric parametrics (cases 3-5, table 1). The grid for the baseline case, as for all the

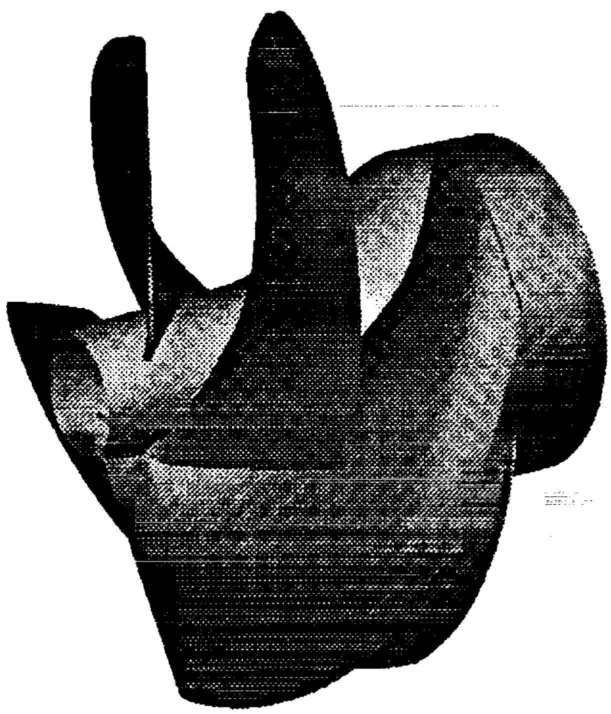

Figure 1 Baseline impeller

Table 1. Impeller Cases Analyzed

case #	1 (baseline)	2	3	4	5	6	7
rpm	2800	2800	2800	2800	2800	2600	2600
tip flow coefficient	.259	.181	.259	.259	.259	.171	.137
tip blade angle							
inlet	13.1	13.1	13.1	20.8	16.3	12.9	12.9
exit	24.1	24.1	29.5	28.6	24.1	32.2	32.2
hub-to-tip radius ratio							
inlet	.185	.185	.185	.185	.185	.400	.400
exit	.525	.525	.525	.525	.525	.700	.700
full blade tip solidity	1.38	1.38	1.27	0.75	0.92	1.66	1.66
leading edge sweep	9.1	9.1	9.1	21.5	21.5	25.6	25.6

other impeller cases, was generated using the code TIGER [4], available from Mississippi State University. TIGER is an extremely efficient and user-friendly turbomachinery grid generation code developed under the guidance of NASA/Lewis Research Center. Typical grids were generated in under one hour. The baseline impeller consisted of four full length blades and four partial blades. However, since TIGER does not have the capability to include partial blades in grids (a capability MSFC is interested in adding) and since we were interested in simplifying the model, it was decided to include only the full blades in the studies. A further simplification was to reduce tip clearance to zero in the model. This simplification was not too far from the actual case where the tip clearance is less than 0.5% of the blade height. The CFD code FDNS [5] developed under MSFC support was used to solve the flowfield on grids that had 44,500 points for cases 1-5 and 91,500 points for cases 6 and 7. Convergenced solutions were typically obtained overnight on NASA/MSFC's CRAY YMP computer, after running from five to eleven CPU hours.

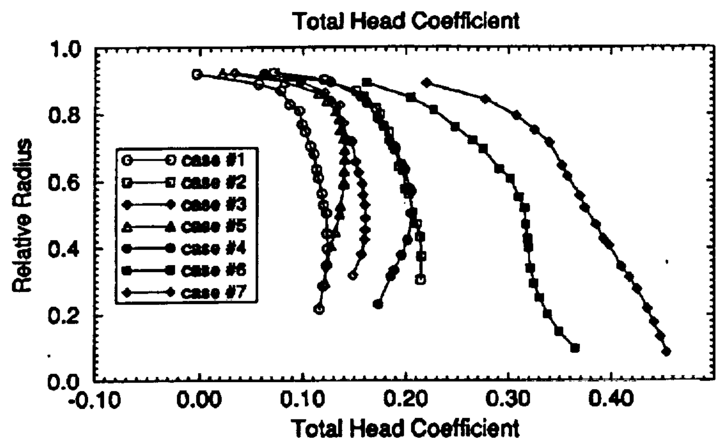

Figure 2. Predicted head coefficient for the simplified cases analyzed

(zero tip clearance, no partial blades)

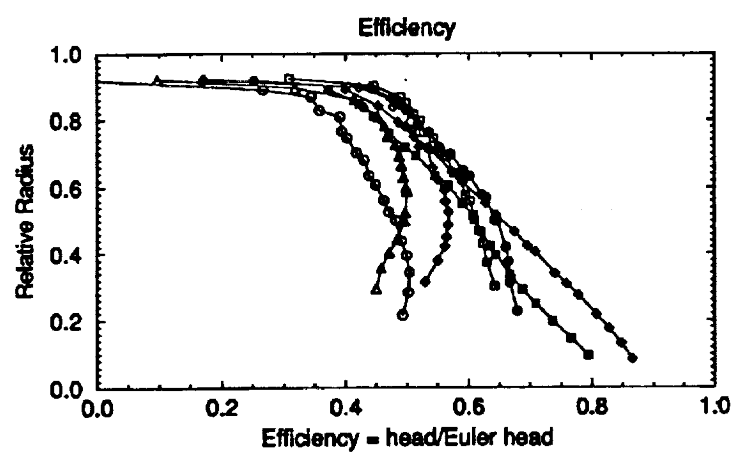

Figure 3. Predicted efficiency for the simplified cases analyzed

(zero tip clearance, no partial blades)

CFD results for the baseline configuration verified initial suspicions that the flow rate provided was too large for the given rpm. The leading edge had a negative incidence throughout the span except near the tip. Because of this, the head coefficient was low (figure 2) as well as the efficiency (figure 3). MSFC then performed four additional analyses in order to determine performance sensitivity to various parameters. Case 2 used the same geometry as the baseline but at a reduced flow (70% of the baseline) such that the blade leading edge had a positive incidence. As expected, the head coefficient increased (figure 2) as well as the efficiency (figure 3) indicating that this reduced flow coefficient was closer to the design point than the baseline. This result implied that to improve pump performance, the nozzle area in the jet-drive should be reduced to increase the backpressure on the impeller and to reduce the flow rate through the pump. Case 3 was run under the baseline conditions but with the blade camber increased by 50% (table 1). The performance predicted for this configuration lies between the performance of case 1 and of case 2. Increasing the camber beyond that of case 3 was deemed not likely to produce further increases in performance due to separation at the blade trailing edge along the hub.

Case 5 was performed prior to case 4. Case 5 assessed the effect of increasing the sweep of the leading edge in the baseline design. Since the sweep was accomplished by cutting back on the baseline blade, the mean blade leading edge angle increased. This produced a modest improvement in performance over the baseline case. Besides these performance improvements, the increased sweep leading edge was deemed desirable from the standpoint of structural robustness. Case 4 retained the increased sweep but featured a completely reprofiled blade. The hub and shroud contour remained unchanged as did the operating parameters. However, the blade was designed using a tip blade angle to incidence ratio consistent with rocket engine design. The hub-to-shroud angle distribution follows a free vortex distribution from inlet to exit (figure 4). The resulting design is predicted to perform

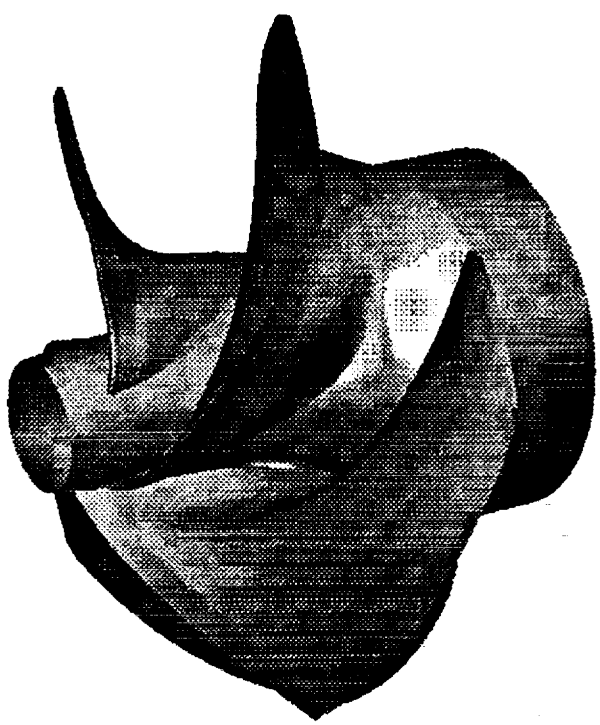

Figure 4. MSFC modified impeller for case 4

nearly as well as the reduced flow case.

Based on these results and on consultation with a third party, NAMJ presented MSFC with a new geometry to analyze (case 6) which featured reprofiled blades and a new hub contour (figure 5). The performance predicted for case 6 was higher than all the previous cases. This was due to be increased hub-to-tip radius ratios and increased solidity that allowed a 75% increase in camber and to the reduced inlet flow coefficient. However, observation of the results indicated that further reduction in flow coefficient was necessary to achieve peak performance. This was modeled in case 7 which featured a 20% reduction in flow from case 6. NAMJ has requested similar MSFC support for the design of the impeller inlet which, at high boat speed, can generate as much thrust as the pump.

CONCLUSION

MSFC is serious about transferring technology to industry. This activity benefited a U.S. company facing foreign competition by using NASA developed technology and expertise. MSFC benefited by expanding its pump analysis experience base and by improving on its CFD analysis procedure. The value of using CFD in the design process has also been demonstrated by providing engineering information on various design concepts and identifying the shortcomings and strengths of each prior to initiating manufacture of the first development article. Not only will this result in a better final product but in a shorter (less expensive) development cycle.

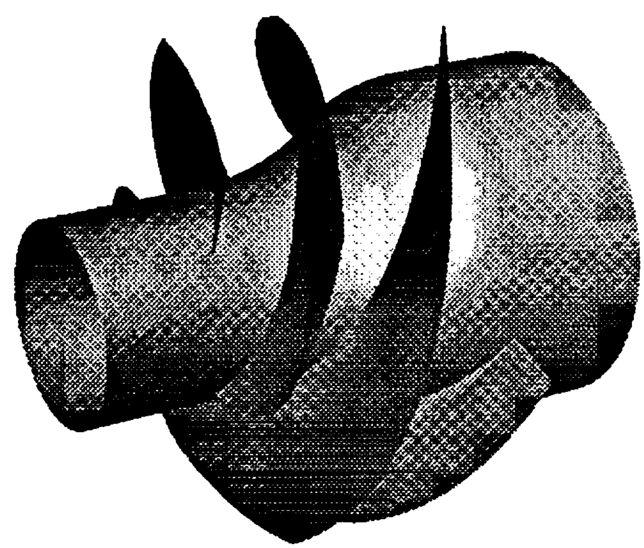

Figure 5. NAMJ redesigned impeller for case 6

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