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A VECTORIZATION OF THE HESS MCDONNELL DOUGLAS
POTENTIAL FLOW PROGRAM NUED FOR THE
STAR-100 COMPUTER

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SUMMARY

The computer program NUED for analysing potential flow about arbitrary three-dimensional lifting bodies using the panel method has been modified to use vector operations and run on the STAR-100 computer. The vectorized version described herein is called NUEDV.

A high speed of computation and ability to approximate the body surface with a large number of panels are characteristics of NUEDV. The new program shows that vector operations can be readily implemented in programs of this type to increase the computational speed on the STAR-100 computer. The virtual memory architecture of the STAR-100 facilitates the use of large numbers of panels to approximate the body surface.

INTRODUCTION

The program NUED utilizes a panel method for analyzing potential flow about arbitrary three-dimensional lifting bodies (ref. 1). The program originator John L. Hess of McDonnell Douglas Corporation developed the program under contracts for the United States Department of the Navy and the National Aeronautics and Space Administration.

The program is designed to run on third generation computers such as the CDC-6600 and CYBER-175. NUEDV is a first attempt to redesign NUED to run efficiently on the STAR-100 computer at Langley Research Center. The objectives have been to decrease the computational run time and to improve the approximation to the body surface by increasing the number of planar quadrilateral elements used. The conversion of NUED is complete and several cases have been run on the STAR-100 computer. The solution times for a test case with 816 elements are compared with those obtained on the CYBER-175 and shown in table 1.

Variable dimension preprocessing has been employed for increasing the number of panels used to approximate the body surface and the case of a body surface with 1464 panels has been calculated by NUEDV.

This report describes the major changes that have been made to NUED to create the vectorized version NUEDV. A comparison of computational times is presented.

STAR-100 PROCESSING SYSTEM

The STAR-100 is a vector processing computer capable of achieving high result rates when a high degree of parallelism is present in the computation. The STAR-100 operates on vectors, most simply thought of as arrays in memory, as opposed to scalars. When an identical operation is to be performed on consecutive

elements in memory (i.e. $c_i = a_i * b_i, i=1, 2, \dots, N$), a vector instruction is issued to perform the operations. Each vector instruction involves a time penalty, called vector start-up, regardless of the length N of the operation. As N increases in size, the operation becomes more efficient since the penalty becomes relatively less important. Another penalty that generally occurs is the necessity for additional storage for temporary vectors instead of temporary scalars.

The goal in designing (or vectorizing) a STAR program is to introduce long vector operations wherever possible. The STAR-100 at the Langley Research Center has one half million words of primary memory with virtual memory architecture. The operating system automatically brings from secondary memory any piece of data which is referred to by the program but does not currently reside in primary memory. Hence, overlay or buffering procedures often coded into large data base programs can be avoided. More detailed information relative to the STAR-100 computer may be found in ref. 2 and 3.

PANEL METHOD FOR POTENTIAL FLOW

The panel method employed by NUED for calculation of potential flow about arbitrary three-dimensional lifting bodies utilizes a distribution of singularity strengths on the surface of the body and solves for the distribution necessary to meet

the specific boundary conditions. Once the singularity strength distribution is known, the flow velocities both on and off the body surface may be calculated.

The procedure used is that of approximating the body surface by a large number of plane quadrilateral elements, over each of which the singularity strength is assumed constant, and replacing the integral equation by a set of linear algebraic equations in which the unknowns are the values of the singularity strengths on the elements.

The panel method as applied in NUED consists of five procedures. These procedures are (1) the initialization, (2) the calculation of the induced velocity matrix for lifting and non-lifting components, (3) the calculation of the normal velocity matrix, (4) the solution of the system of linear equations for singularity strengths, and (5) the calculation of the final velocities.

The major revisions made in NUEDV are in the solution of the system of linear equations, the calculation of the induced velocity matrix, and the calculation of the final velocities.

VECTORIZATION AND PERFORMANCE EVALUATION OF NUEDV

The largest amount of time in NUED is spent in the solution of a system of real linear algebraic equations for the values of singularity strengths represented by the matrix equation $Ax=B$. In

the test case for the V45 tail assembly (fig. 1), A is a square matrix of coefficients 816×816 , X is a rectangular solution matrix and B is a rectangular matrix 816×19 whose columns contain the right hand side constant vectors. In NUEDV subroutine BLKGELIM, a version of the STAR math library subroutine GELIM designed for STAR's virtual memory architecture (ref. 4), is used to replace the COLSOL subroutine from NUED. The A and B matrices are not explicitly written on files of secondary storage but are stored in directly addressable arrays to be brought in as needed by BLKGELIM.

The time required in NUED for this solution is 301.49 seconds on a CYBER-175. The vectorized solution in NUEDV requires 23.83 seconds on the STAR.

The second largest amount of time in NUED is spent in the calculation of the induced velocity matrix for lifting and non-lifting components. In NUEDV subroutines VFMNLF, VFMLFT, NEAR, and WNEAR from NUED are replaced with vectorized subroutines written in SL/1 (ref. 5). SL/1 is a programming language which has been designed especially for STAR-100 applications programming. These routines compute the velocity matrix for all control points in vector operations. These control points are classified as being in the near field, the intermediate field, or the far field. For the test case there are 816 control points, with 16 percent in the near field, 17 percent in the intermediate field, and 67 percent in the far field.

Generally, in cases where large numbers of quadrilaterals are used to approximate the body surface, as many as 90 percent of the induced velocities are in the far field, with about 5 percent in the intermediate field and 5 percent in the near field. A test has been performed classifying all the elements as near field and enabling the maximum vector length of 816 to be used. This test shows that the increase in the number of calculations required by the use of the longer exact velocity formulas in the near field is such that the increased vector length does not improve the performance of the test case. The larger the percentage of the points in the far field the longer the vector length used for those calculations and the result of classifying all points as near field would be a further deterioration in performance.

The STAR-100 has a virtual memory architecture which means that the user has at his disposal an address range which far exceeds the physical size of central memory. The operating system automatically brings from disk to central memory any information required in the execution of the program which does not already reside there. The information resides in one or more blocks of data called pages, and the process of retrieving the pages from disk, placing them in central memory, and if necessary removing other pages to make room for them is called paging. The page size is either 512 words (64 bits) or 65536 words. The entire block must be transferred if any one part

of it is needed. To limit the amount of paging it is desirable that the data be stored in the order in which it is referenced and that when a new page is brought into central memory, all or most of that page be used before it is removed.

In NUEDV induced velocity components V_x , V_y , V_z , are not written on files of secondary storage but are stored in directly addressable arrays to be paged in as needed for the calculation of the normal velocity matrix and the final velocities. The three velocity components generally are referenced in the same equation. If these components are stored in three two-dimensional arrays 816×816 it is necessary that each component $V_x(I,J)$, $V_y(I,J)$, $V_z(I,J)$, will reside on a separate large page. However, if the velocity components are stored in one three-dimensional array $816 \times 3 \times 816$ the J th column of V_x is stored followed by the J th column of V_y and finally V_z . Hence, the three columns which are referenced together will usually reside on the same large page and the paging is greatly reduced.

The time required in NUED for the calculation of the induced velocity components is 112.80 seconds on CYBER-175. The vectorized calculation in NUEDV requires 37.53 seconds on STAR.

The third largest amount of time in NUED is spent in the subroutine COMFLO in calculation of the final velocities and printing of results. The components of the fluid velocity at the null point of each element are obtained by multiplying the

velocity components induced by the elements by the proper value of the singularity strengths, summing the result over all elements and adding the components of the onset flow.

In NUEDV subroutine COMFLO is replaced with a vectorized subroutine. The induced velocity components are not read from files of secondary storage but are paged in from the directly addressable three-dimensional array $816 \times 3 \times 816$. Vector operations of length 816 replace scalar operations in the calculation of the components of the fluid velocity of each element.

The time required in NUED for the final velocity calculations for the test case with 3 onset flows and printing is 16.79 seconds on CYBER-175. The vectorized calculation in NUEDV requires 23.04 seconds on STAR. This time includes the generation of printed output which requires more time on STAR-100 than on CYBER-175.

The total time required on the CYBER-175 for the test case of 816 control points is 438.88 seconds. With the vectorization of the selected subroutines the STAR-100 time required is 111.54 seconds, for a decrease in computational time by a factor of 3.93 as compared to the time required on the CYBER-175.

NUEDV demonstrates that vector operations can readily be implemented to increase the computation rate of the panel method for analyzing potential flow about arbitrary three-dimensional lifting bodies.

IMPROVED SURFACE DEFINITION

Variable dimension preprocessing has been used to vary the dimensions of the storage arrays required as the number of panels is increased. Employing the virtual memory architecture of the STAR-100, these storage arrays may be increased to a size which is sufficient for the number of panels required to adequately describe the body surface. In the case of the configuration of a helicopter body and sting (fig. 2) an adequate surface definition was not possible with the 1100 panel limit imposed by the CYBER-175. The number of panels was increased to 1464 and the calculations were completed successfully on the STAR-100 in a CPU time of 189 seconds.

CONCLUDING REMARKS

The computer program NUED for analyzing potential flow about arbitrary three-dimensional lifting bodies has been modified to use vector operations and run on the STAR-100 computer. The vectorized version is called NUEDV.

The large system of linear equations for surface source density is solved with an efficient STAR subroutine BLKGELIM. The induced velocity matrix is calculated by vectorized subroutines written in SL/1. The matrix is stored in a directly addressable three-dimensional array. Vector operations replace

scalar operations in the calculation of the components of the fluid velocity of each element. Increased speed of computation and the use of large numbers of panels to approximate the body surface are characteristics of NUEDV.

A decrease by a factor of 3.93 as compared to the computational time required on the CYBER-175 has been demonstrated on the STAR-100.

Procedure	Time (sec) on CYBER-175	Time (sec) on STAR-100	Ratio of CY-175 CPU Time to STAR-100 CPU Time
Initialization	3.83	20.78 *	.18
Induced Velocity	112.80	37.53	3.01
Normal Velocity	3.97	6.36 *	.62
Source Density	301.49	23.83	12.65
Final Velocity and Output	16.79	23.04	.73
TOTAL	438.88	111.54	3.93

* NOT VECTORIZED

TABLE 1.

TIMES FOR V45 TEST CASE

VECTOR LENGTH 816

REFERENCES

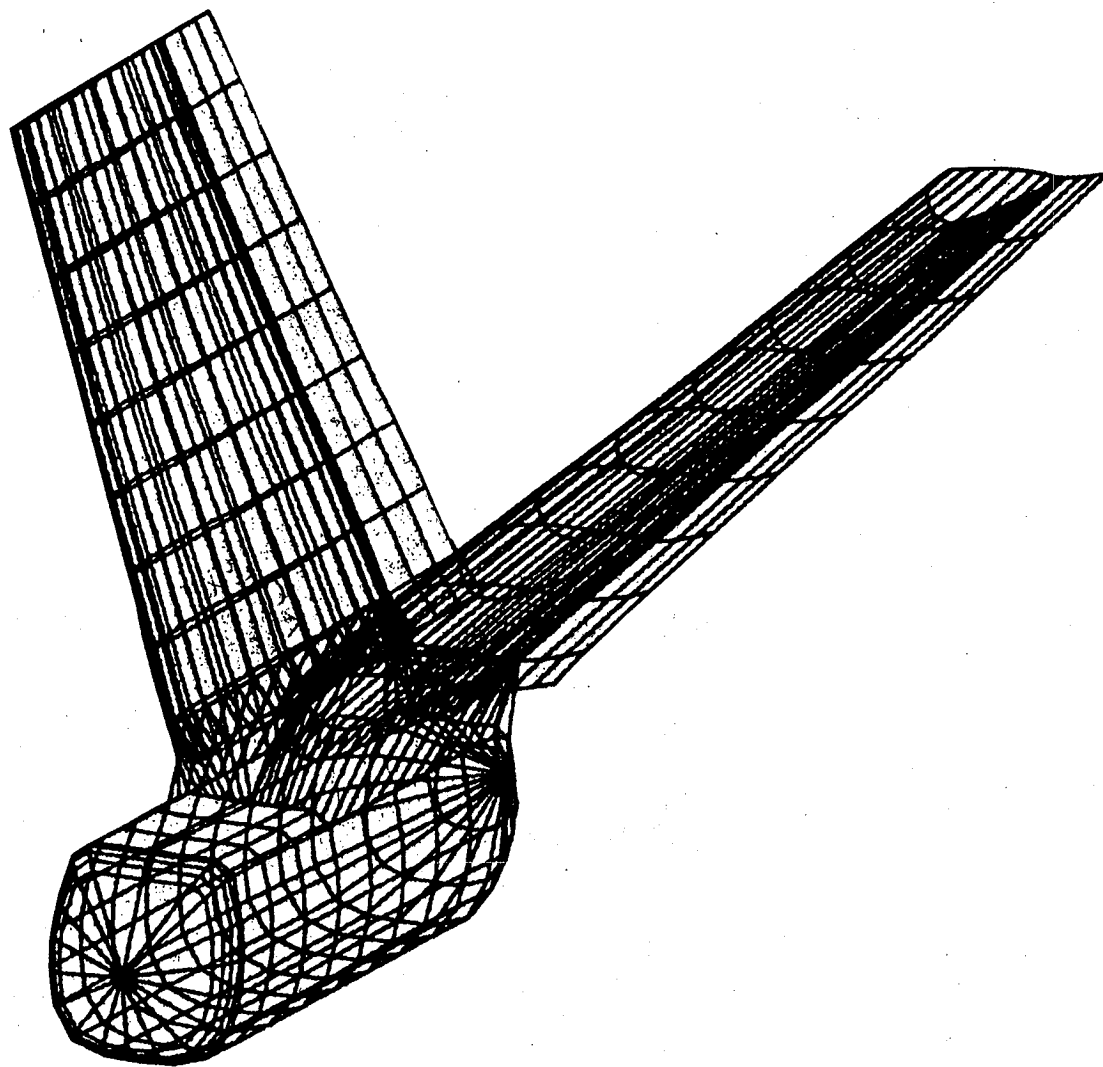
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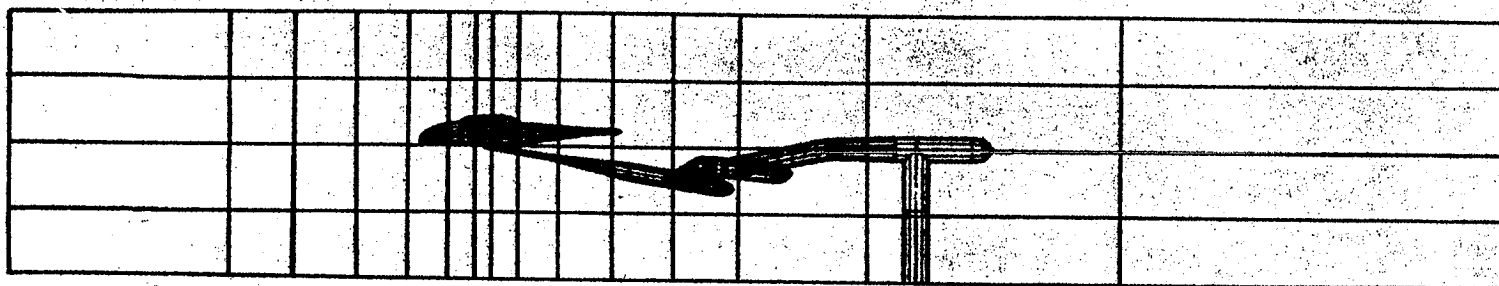
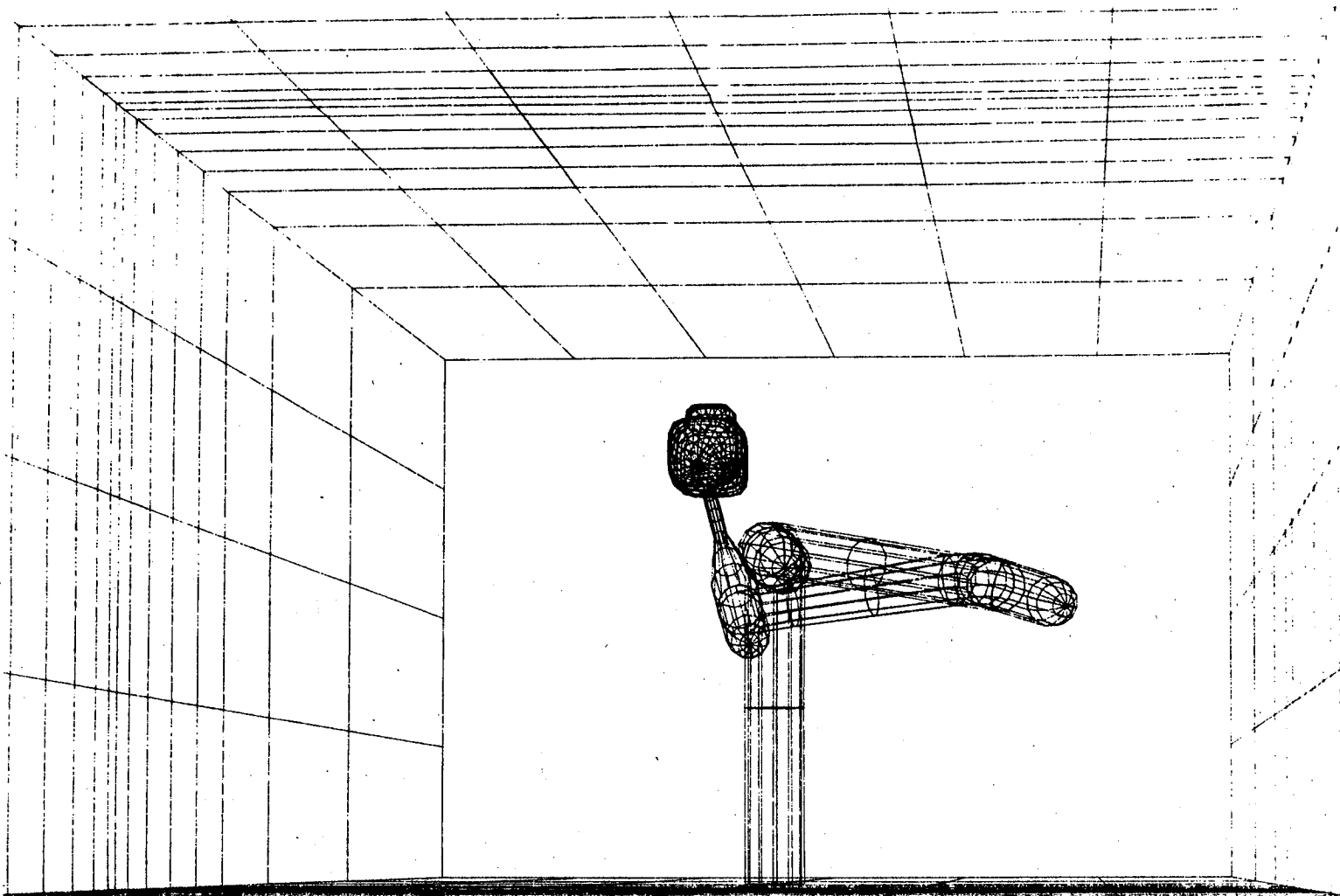
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V 45 TAIL ASSEMBLY

Figure 1



HELICOPTER BODY AND STING IN VSTOL WIND TUNNEL

1464 Panels

Figure 2

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