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Improving the high frequency performance of AVAST

D.P. Brennan
J.D. Covill
Martec Limited

Prepared by:
Martec Limited
1888 Brunswick Street, Suite 400
Halifax, Nova Scotia B3J 3J8

Contract number: W7707-02-1894/001/HAL
Contract Scientific Authority: L.E. Gilroy, Group Leader Acoustic Signatures, (902) 426-3100 x365

Defence R&D Canada – Atlantic

Contract Report

DRDC Atlantic CR 2005-051

August 2005

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IMPORTANT INFORMATIVE STATEMENTS

Abstract

The development and incorporation of the latest enhancements to the AVAST code are described. The purpose of this work was to make the modeling of the physical environment more realistic, while ensuring that the code runs as efficiently as possible. To this end several new features have been added. These include upgrading the existing library of fluid panels to in order to provide user's with higher order elements better suited for modeling structures with a significant degree of curvature, developing a UNIX version of the AVAST software designed to take full advantage of DRDC's multi-processor SUNFIRE workstation, and the implementation of a high frequency Kirchhoff scattering capability. In addition, a series of parametric studies involving sound scattered from rigid structures having impedance type boundary conditions were also conducted using the latest version of the AVAST solver.

Résumé

Le présent rapport décrit l'élaboration et l'intégration des dernières améliorations au code AVAST. Le but des présents travaux est de rendre plus réaliste la modélisation de l'environnement physique, tout assurant une exécution aussi efficace que possible du code. Pour ce faire, plusieurs nouvelles fonctionnalités ont été ajoutées, dont la mise à niveau de la bibliothèque actuelle de panneaux de fluides afin de fournir aux utilisateurs des éléments d'ordre supérieur mieux adaptés aux structures de modélisation avec un haut degré de courbure, le développement d'une version UNIX du logiciel AVAST conçue pour tirer pleinement profit du poste de travail multiprocesseur SUNFIRE de RDDC et l'implémentation d'une capacité de diffusion à grande fréquence, fondée sur le modèle de Kirchhoff. De plus, une série d'études paramétriques portant sur des ondes sonores diffusées par des structures rigides présentant des conditions d'impédance aux limites ont également été réalisées au moyen de la version la plus récente du mécanisme de solution AVAST.

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Table of contents

Abstract i

Table of contents iii

List of figures v

1. Introduction 1

2. Upgrade AVAST Surface Panel Library 2
   - 2.1 Super-Parametric Fluid Panel Formulation 2
   - 2.2 Input Format of Super-parametric Fluid Panel Elements 2
   - 2.3 Illustrative Examples 3
     - 2.3.1 Sphere Model 3
     - 2.3.2 Cylinder Model 3
   - 2.4 Conclusions 3

3. Develop a Unix Version of the AVAST Solver 10
   - 3.1 First Port 10
   - 3.2 Incorporation of BLAS Libraries to AVAST Solver 10
   - 3.3 Compiler and OS Settings - SunFire 11
   - 3.4 Results and Conclusions: 11
   - 3.5 Future Directions 12

4. Investigate the Implementation of a Kirchhoff Scattering Capability in AVAST 13
   - 4.1 Kirchhoff Approximation 13
   - 4.2 AVAST Implementation of the Kirchhoff Approximation 14
   - 4.3 Recommendations 14

5. Perform a Series Target Strength Analysis Using Rigid Cylinder Models Having Impedance Type Boundary Conditions 22
   - 5.1 Model Setup 22
   - 5.2 Results 22
   - 5.3 Conclusions 23

6. Review the High Frequency Target Strength Performance of the AVAST Solver 30
  6.1 Panel integration routines 30
  6.2 Burton and Miller Method 31
7. References 32
List of symbols/abbreviations/acronyms/initialisms 33
Glossary 34

List of figures

Figure 2.1. Target Strength Analysis of Sphere: Ka = 1 (low order vs high order fluid panels) 4

Figure 2.2. Target Strength Analysis of Sphere: Ka = 2 (low order vs high order fluid panels)5

Figure 2.3. Low Order Panel Model of theCylinder 6

Figure 2.4. Super-parametric Model of the Cylinder 7

Figure 2.5. Location of Field Point Relative to the Cylinder (Field Points Oriented Along the Path of the Arc / The Root of the Arrow Represents a Field Point Located at Zero Degrees) 8

Figure 2.6. Comparison of Target Strength Prediction Using Four and Eight Noded Panels 9

Figure 4.1. AVAST Model of DRDC Atlantic's Acoustic Cylinder 15

Figure 4.2. AVAST Kirchhoff Scattering Results at 5 kHz (Full Illumination of Target) 16

Figure 4.3. AVAST Kirchhoff Scattering Results at 7.5 kHz (Full Illumination of Target 17

Figure 4.4. AVAST Kirchhoff Scattering Results at 10 kHz (Full Illumination of Target) 18

Figure 4.5. AVAST Kirchhoff Scattering Results at 10 kHz: Full Illumination vs Partial Illumination 19

Figure 4.6. Kirchhoff Scattering (with Illumination Correction) vs Conventional BE Formulation 20

Figure 4.7. A Comparison of AVAST Kirchhoff and DSTO Results for Submarine Sail at 4 kHz 21

Figure 5.1. Variation of Forward and Back Scattered Target Strength due to Changes in Impedance (240Hz) 24

Figure 5.2. Variation of Target Strength due to Changes in Impedance: Polar Plot (240Hz) .. 25

Figure 5.3. Variation of Forward and Back Scattered Target Strength due to Changes in Impedance (480Hz) 26

Figure 5.4. Variation of Target Strength due to Changes in Impedance: Polar Plot (480Hz) .. 27

Figure 5.5. Variation of Forward and Back Scattered Target Strength due to Changes in Complex Impedance (240Hz) 28

Figure 5.6. Kirchhoff Scattering (with Illumination Correction) vs Conventional BE Formulation 29

Figure 6.1. Kirchhoff Scattering (with Illumination Correction) vs Conventional BE Formulation 31

1. Introduction

Phases one though ten of the DREA/Martec collaborative research in underwater/structural acoustics has resulted in the development of a series of computer programs, collectively named AVAST, for the numerical prediction of the acoustic radiation and scattering from floating or submerged elastic structures immersed in either infinite, half-space or finite depth fluid domains. AVAST combines both the finite element method (FEM) for the structure and the boundary integral equation technique for the fluid. The finite element method (FEM) is used to predict the natural frequencies and related mode shapes of the structure in-vacuo. The boundary integral equation method (BIEM) is used to generate a system of equations relating structural displacements to fluid acoustic pressures.

In an attempt to make the modeling of sound radiated and scattered from structures more realistic, several enhancements have recently been incorporated into the previously existing AVAST suite. These include upgrading the existing library of fluid panels to in order to provide user's with higher order elements better suited for modeling structures with a significant degree of curvature, developing a UNIX version of the AVAST software designed to take full advantage of DRDC's multi-processor SUNFIRE workstation, and the implementation of a high frequency Kirchhoff scattering capability. In addition, a series of parametric studies involving sound scattered from rigid structures having impedance type boundary conditions were also conducted using the latest version of the AVAST solver.

In the discussion which follows, details concerning the development and incorporation of these latest enhancements to the AVAST suite will be presented.

2. Upgrade AVAST Surface Panel Library

During a recent set of numerical trials, which involved comparing target strength predictions generated by the AVAST code to those predicted using an axisymmetric boundary element based code, it was found that in cases involving high frequencies, the AVAST code produced high “side lobes” which were not predicted by the axisymmetric code. After careful review of these results it has been suggested that one possible source of the discrepancy between the two codes could be due, in part, to the limitations of using low order boundary element panels when attempting to model structures having a high degree of curvature. As a result, it has been proposed that the current AVAST panel library be upgraded to allow for the use of higher order super-parametric fluid elements.

In the discussion which follows, details related to the implementation of the new AVAST family of higher order fluid panels will be provided.

2.1 Super-Parametric Fluid Panel Formulation

There were a number of reasons for implementing a family of “super” parametric fluid panels over other types of high order panels. The main reason for doing so is due to the relative ease of incorporating these elements within the current framework of the AVAST code. In the case of super-parametric elements, the order of the approximation for geometry is higher than that used for the field function (i.e.: the acoustic pressure). As a result, the acoustic pressure can be represented as a constant over the surface of any given fluid panel using super-parametric fluid panels (the current set of low order fluid panels also assume that pressure can be assumed constant over any given fluid panel). Since the new set of super-parametric elements share the same number of pressure unknowns per panel as the low order fluid panels, the same routines responsible for matrix assembly and decomposition developed and validated in previous AVAST contracts, have been used for cases involving the super-parametric element. If isoparametric fluid element were to be used, a completely new set of assembly and decomposition routines would have to be developed. This is due to the fact that for isoparametric panels, the same order of approximation is used for both the geometry and pressure field.

2.2 Input Format of Super-parametric Fluid Panel Elements

In order for user’s to take advantage of these newly developed fluid panels a special “superparametric panel” section must be provided in the AVAST input file (replacing the “surface panel” section used by earlier versions of the AVAST solver). In this section, the connectivities of super-parametric panels must be defined. In order to minimize the changes required to incorporate these elements into the latest version of the AVAST code, user’s must supply a total of nine nodes for each panel connectivity, regardless of the panel order.

AVAST will determine the exact order by checking for duplicate node numbers in the connectivity list. For example, if a 6-noded panel is to be defined, nodes 6-9 in the connectivity list will be repeated. If a 4-noded panel is to be created, nodes 4-9 will be repeated.

2.3 Illustrative Examples

2.3.1 Sphere Model

In order to demonstrate the accuracy of the new super-parametric AVAST acoustic fluid panel, a series of AVAST target strength analysis were conducted using models of spheres discretized using both low order quadrilaterial panels and high order eight-noded super-parametric fluid elements. A comparision of the results generated by both element formulations, provided below in Figures 2.1 and 2.2, clearly show excellent agreement between the two sets of results.

2.3.2 Cylinder Model

In a second set of trials, a series of target strength analyses were conducted using models of a cylinder (2 m length / 0.25 m radius) discretized using both low order quadrilaterial panels (see Figure 2.3) and high order eight-noded super-parametric fluid elements (see Figure 2.4). Target strength predictions were made for a set of wave numbers ranging from 0.5 to 3.5. The positions of the field points relative the model are provided in Figure 2.5 (the source is located at a distance of 100 m off broadside). The results for both models is provided below in Figure 2.6. Close examination of the results clearly shows very close agreement, which is somewhat unexpected given that the super-parametric panel provides a much more accurate representation of the geometry.

2.4 Conclusions

Due to the fact that target strength predictions generated using both low order and super-parametric panel formulations appear almost identical, it is not clear whether the additional computational overhead associated with the use of the super-parametric elements is justified.

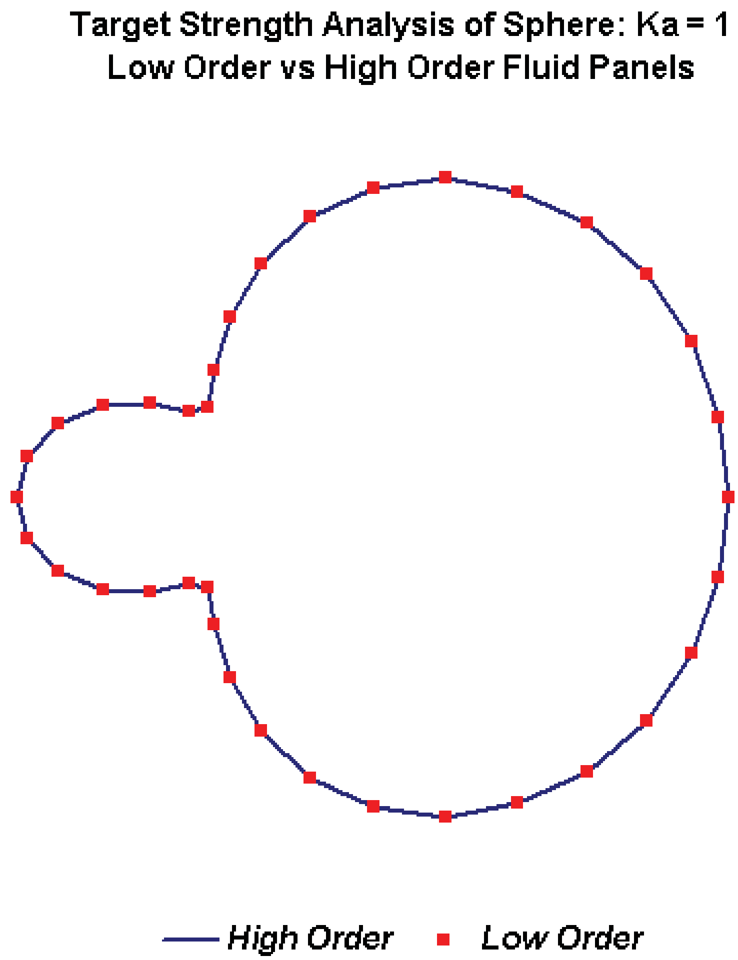

Figure 2.1. *Target Strength Analysis of Sphere: Ka = 1 (low order vs high order fluid panels)*

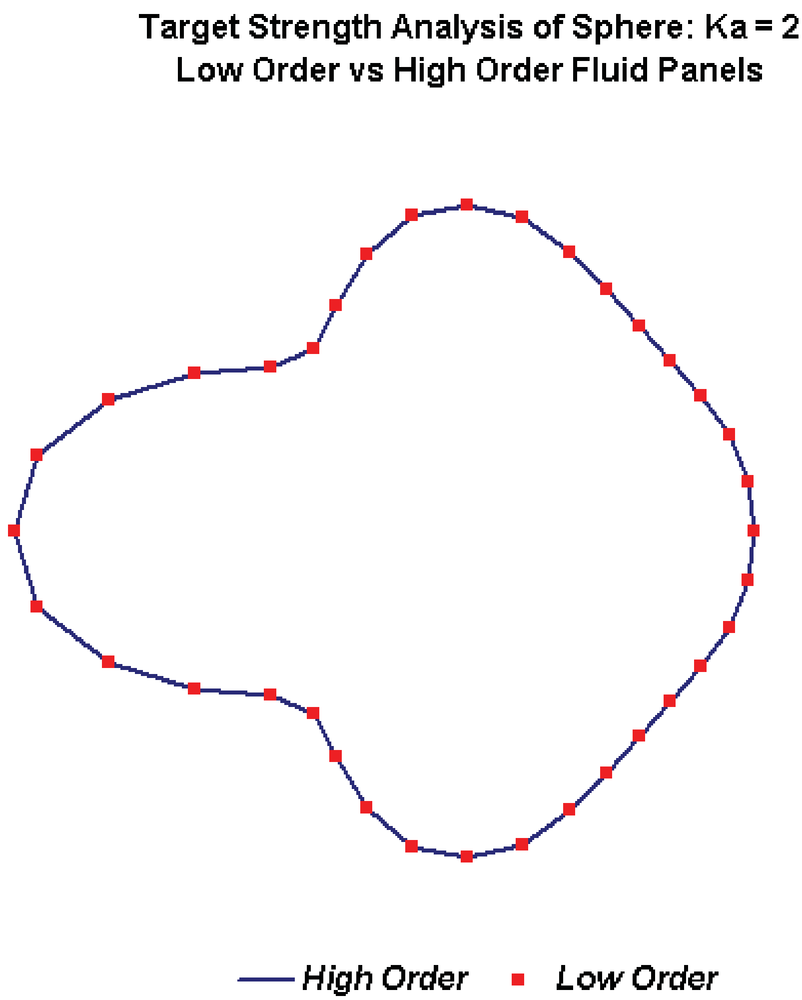

Figure 2.2. *Target Strength Analysis of Sphere: Ka = 2 (low order vs high order fluid panels)*

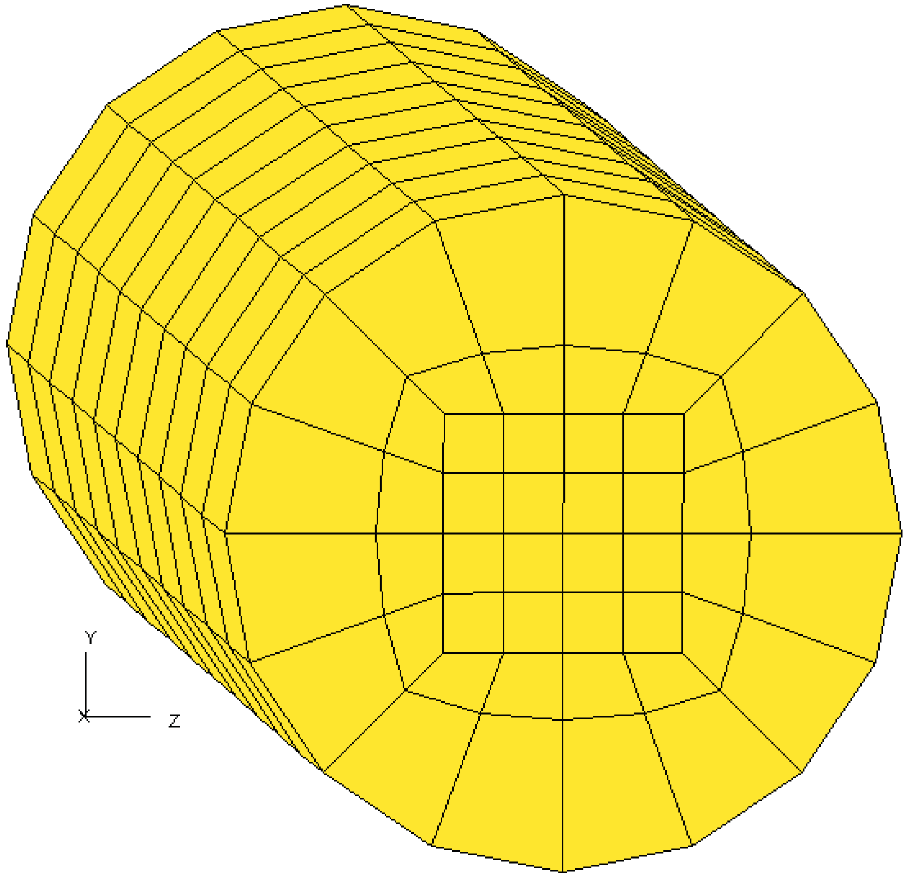

Figure 2.3. *Low Order Panel Model of theCylinder*

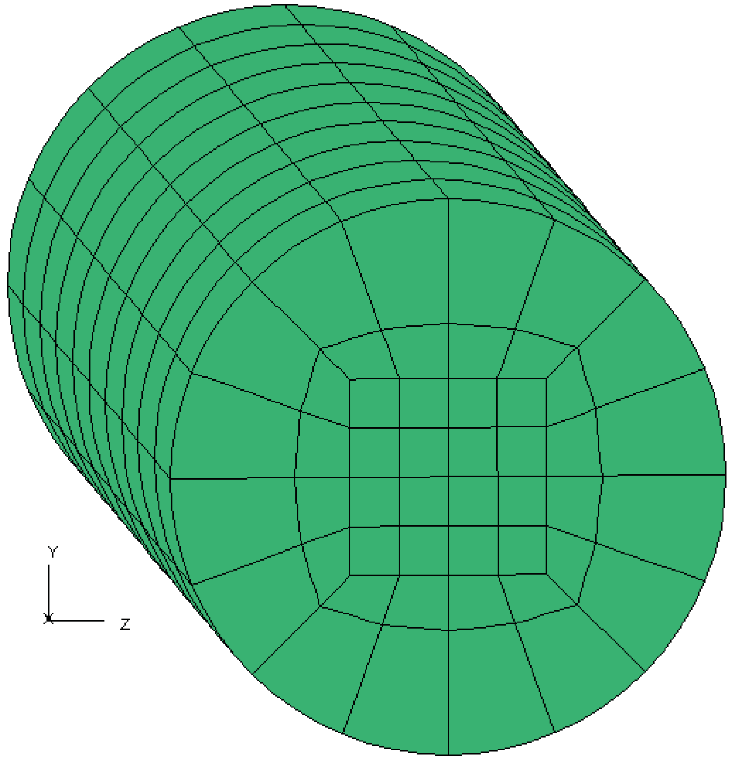

Figure 2.4. *Super-parametric Model of the Cylinder*

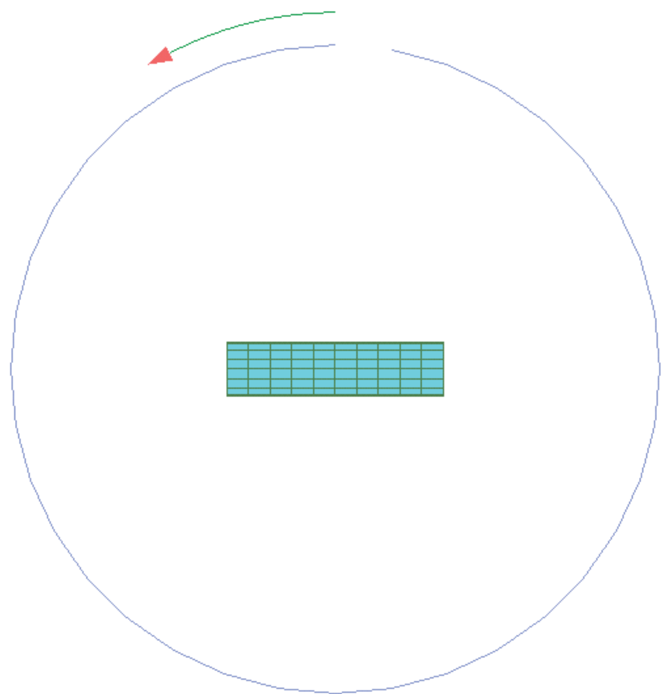

Figure 2.5. Location of Field Point Relative to the Cylinder (Field Points Oriented Along the Path of the Arc / The Root of the Arrow Represents a Field Point Located at Zero Degrees)

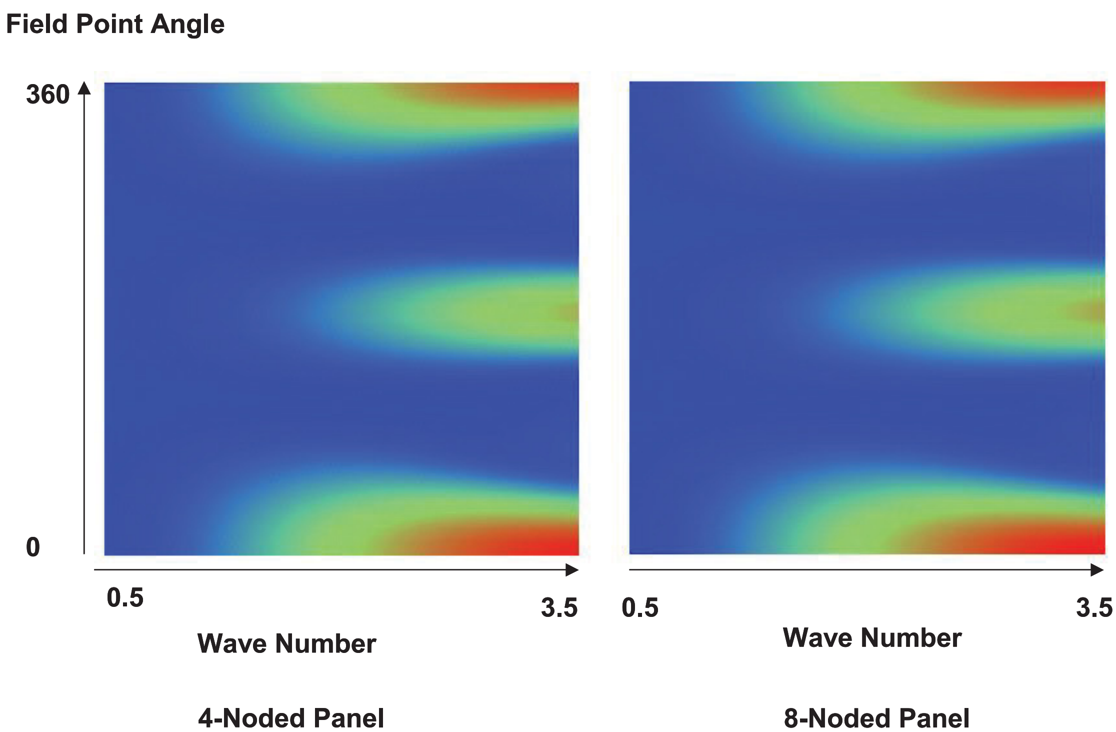

Figure 2.6. Comparison of Target Strength Prediction Using Four and Eight Noded Panels

3. Develop a Unix Version of the AVAST Solver

DRDC Atlantic's Sunfire V880 server is an 8 CPU (UltraSPARC III, 64bit, 750 MHz) system currently configured with 16 GB RAM. The system is a multi-symmetric design meaning that the processors are independent on one another but share common memory.

3.1 First Port

The AVAST code has been developed over many years. Written originally in Fortran 77 it has been under continuous development for many years and now takes advantage of many of the features found in the Fortran 95 language specification standard (such as dynamic memory allocation and user defined types). In recent years, the development has taken place on WinTel PC using the Hewlett Packard Visual Fortran Compilers (formally Compaq and prior to that formally Digital). The current release of the compiler is 6.6b. The SunFire's Fortran 95 compiler was a Beta Release and bundled as part of the Sun One Developer System.

The AVAST source code was loaded onto the Sunfire and compiled. No major modifications were required with only a few minor syntax modifications required (generally relating to line lengths and occasional 'type' mismatches not identified by the HP compiler). Some small test cases were run with the solutions proving identical.

3.2 Incorporation of BLAS Libraries to AVAST Solver

The AVAST solver was then modified to take advantage of the BLAS routines. This work was carried out simultaneously on the WinTel and SunFire platforms. It was our belief that by using the BLAS (Basic Linear Algebra Subprograms) routines on the PC and the Sun Performance Library (SPL) on the SunFire a significant speed increase could be realized. Specifically, the SPL is a suite of highly optimized and Sunfire-tuned mathematical subroutines based on the standard issues of LAPACK, BLAS, FFTPACK, VFFTPACK, and LINPACK libraries. Further, the SPL is specifically designed for use on the SunFire's SPARC architecture in both serial and parallel (i.e. multiprocessor) states with no internal modifications (i.e. manual memory segmentation, synchronization issues etc) required to the original code. Test problems running on both platforms proved identical.

3.3 Compiler and OS Settings - SunFire

The FORTRAN statement ‘USE SUNPERF’ (first line after subroutine/function declaration) is required to prototype the calls to the Sun Performance library. It is recommended for all calls to the SunPerf library as a method of checking interface arguments correctness)

The Fortran compiler is invoked with the following option

f90 –dalign –xparallel–lsunperf_mt –mt *.f –xlic_lib=sunperf –o avast

where:

Option	Significance
–dalign	Force COMMON block data alignment to allow double word fetch/store
–xparallel	Parallelize loops with “-autopar -explicitpar -depend “ combinations
-xlic_lib=sunperf_mt	Link with Sun Performance Library – Multi-Thread Version
-mt	
-o avast	Names executable image to avast

Several OS environment commands are required to allow the process to run in a parallel environment.

These are:

setenv PARALLEL= 8
setenv OMP_NUM_THREADS=8

3.4 Results and Conclusions:

Results are at best mixed. The DRDC SunFire is configured with 8 processors. With the small, medium and larger test problems it was found that 4 processors appeared to be provide the best performance. The overhead spend managing 6 or 8 processors exceeded the performance gain with wall clock time marginally increasing compared to the 4-processor usage.

Using the automatic parallel features of the compiler saw no appreciable gain running on multiple CPUs verses scalar (i.e. single CPU). The execution of small to medium size problems was just as fast on high end PCs as it was on the SunFire. It is important to note that 32 bit Intel based PC's are limited to 2-4Gb RAM while a fully configured SunFire supports 32Gb of RAM and hence large problems can be run on the SunFire due to its larger memory address space.

It is important to note that in this phase of porting the AVAST code to the SunFire it was decided that a first approach would be to use the SunPerf library and use the compiler parallelizing capabilities. The SunFire Fortran 95 compiler was a beta release, which may have contributed to the lacklustre parallelisation.

3.5 Future Directions

Discounting the automatic approach as supplied by the compiler, hand-coding using the OpenMP standard to execute the 'do loop' structures across multiple processors appears to be the best long term approach to making a reliable executable image. The compiler is very conservative about multithreading loops. If there is the slightest possibility of data dependencies, it will refuse to do it -xparallel is used. Function calls within loops, *if* statements that depend on variables which change in the loop, and many other features will be considered "dangerous" and inhibit parallelization.

4. Investigate the Implementation of a Kirchhoff Scattering Capability in AVAST

The underlying boundary element based algorithms employed by the AVAST solver to model and predict acoustic pressures radiated and scattered from marine structures are best suited for low frequency excitations. Attempts to model the acoustic response at higher frequencies can quickly overwhelm the memory/disk-space resources of most desktop computers, primarily due the modelling requirement of maintaining a minimum of twelve to sixteen panels per acoustic wavelength.

Fortunately, a number of computational techniques, developed specifically for high frequency target strength analysis, have been reported in the literature [1-3]. One in particular, known as the Kirchhoff scattering technique (KST), has been used recently to model the acoustic target of a generic submarine [3]. The success of that effort has now led to the development of a Kirchhoff-based scattering capability within the framework of the current AVAST code.

In the discussion which follows, details related to the implementation of the Kirchhoff scattering capability in an upgraded version of the AVAST code will be provided. This is followed by a set illustrative examples which provide a comparison of target strength predictions generated by both the conventional boundary element and Kirchhoff based approaches.

4.1 Kirchhoff Approximation

The Kirchhoff approximation developed for the purposes of this study is based on the work published by Schneider, Berg, Gilroy, Karasalo, MacGillivary, Morshuizen, and Volker [3]. In their approach, the far-field pressures produced by the scattering object can be approximated by the following expression:

$$p_{scat}(\vec{r}) = \frac{-ik}{4\pi} \oint_s \frac{e^{-ik|\vec{r}-\vec{r}_s|}}{|\vec{r}-\vec{r}_s|} p_{inc}(\vec{r}_s)\Re(\phi_{inc})[\cos(\phi_{scat}) + \cos(\phi_{inc})]ds \qquad (4.1)$$

where $\Re$ represents the plane wave reflection coefficient which relates the incident and scattered fields on the body surface (i.e.: $p_{scat}(\vec{r}_s) = \Re p_{inc}(\vec{r}_s)$). For the purposes of this study, since only rigid objects will be considered, $\Re$ is assumed to be equal to 1. Although not explicitly defined in the Schneider report, it is assumed that ϕ_{scat} and ϕ_{inc} are assumed to represent the angle between the surface normal and the vectors representing relative position of the field and source points with respect to panel centroid.

A formulation quite similar to that provided above in Equation (4.1) has also been derived by Fawcett [1] for cases restricted to surfaces without sharp corners or edges:

$$p_{scat}(\vec{r}) = 2\int_s \frac{\partial G(\vec{r}\ ,\vec{r}_s)}{\partial n} p_{inc}(\vec{r}_s)ds \qquad (4.2)$$

4.2 AVAST Implementation of the Kirchhoff Approximation

Due to the relative simplicity of the Kirchhoff formulations provided above in Equations (4.1) and (4.2), both expressions have been implemented in the latest version of the AVAST code (both Bistatic and Monostatic). Tests involving target strength predictions using a model of the DRDC Atlantic acoustic cylinder (assumed to be rigid –see Figure 4.1) over a range of frequencies show excellent agreement between the two formulations (see Figures 4.2 – 4.4). For all cases considered, the field points were located 1000 m from the cylinder center and positioned on a transverse plane cutting the cylinder mid-way along its longitudinal axis. The acoustic source was positioned at a distance of 10000 m from the cylinder center (oriented at 12 o'clock - see Figure 4.2).

In addition to the Kirchhoff formulations described above, an additional formulation, which set the incident pressure to zero on portions of the surface not directly illuminated by source, was also implemented into the AVAST code. A comparison of the bistatic target strength computed by this "illumination corrected" version and the non-modified form of the Schneider formulation is provided in Figure 4.5 for an excitation frequency of 10 kHz. A comparison between the "illumination corrected" and conventional boundary element target strength modelling algorithms is provided in Figure 4.6. Note that in Figure 4.6 the agreement is relatively good in the back scattering direction but relatively poor in the forward scattering direction.

In addition to the cylinder target strength results presented above, the AVAST Kirchhoff scattering algorithm was also used recently to model the target strength of a generic submarine sail at 4 kHz. A comparison of the AVAST predictions with those computed using DSTO's high frequency target strength analysis code show excellent agreement (see Figure 4.7).

4.3 Recommendations

While the target strength predictions generated using the algorithm described above appear to agree closely with those produced by other codes, this current formulation does not account for free surface or shallow water effects. As a result, it is recommended that the AVAST Kirchhoff scattering algorithm be upgraded in order to provide users with a capability for modelling these types of environmental effects.

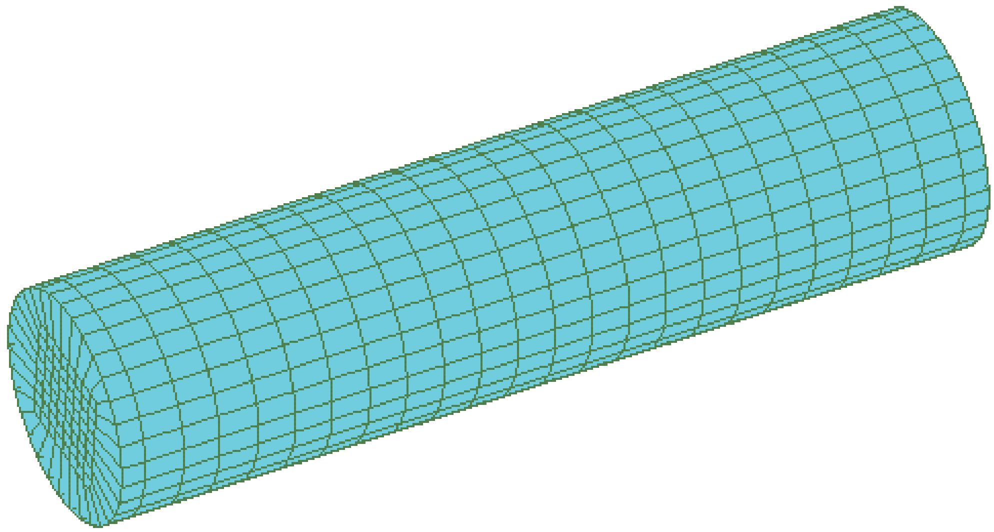

Figure 4.1. *AVAST Model of DRDC Atlantic's Acoustic Cylinder*

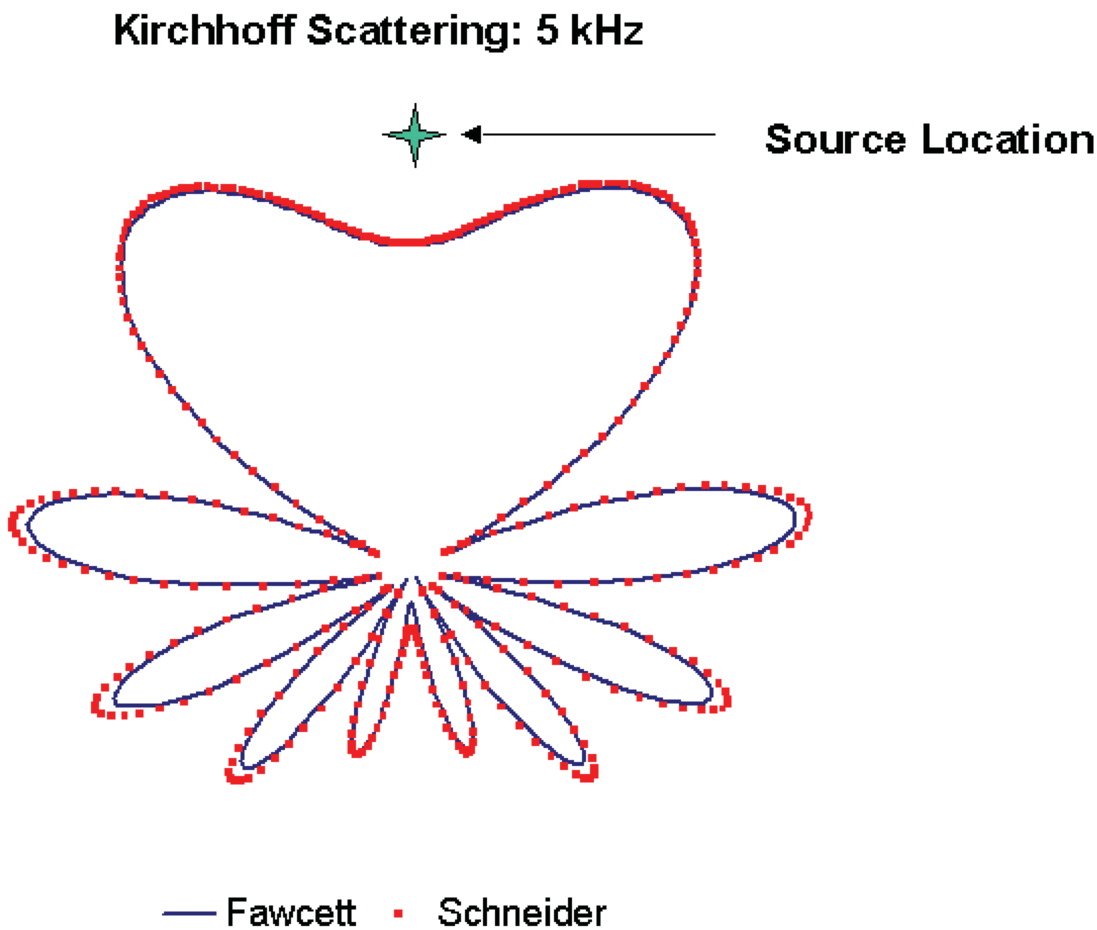

Figure 4.2. *AVAST Kirchhoff Scattering Results at 5 kHz (Full Illumination of Target)*

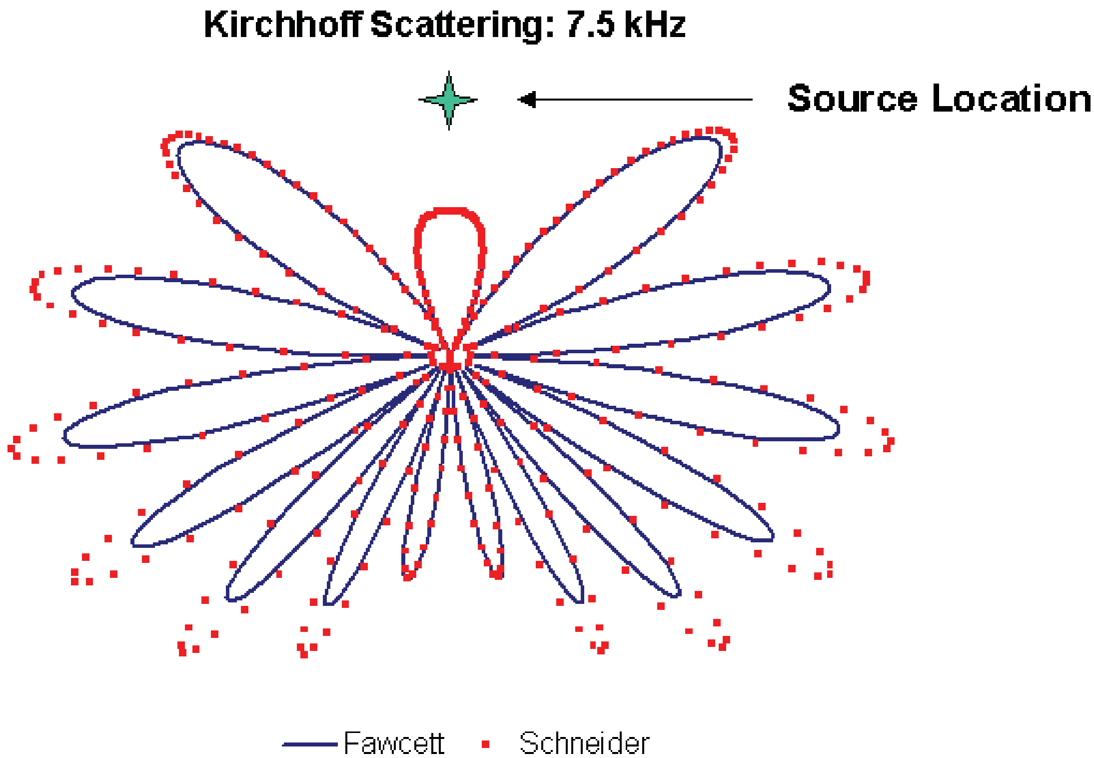

Figure 4.3. *AVAST Kirchhoff Scattering Results at 7.5 kHz (Full Illumination of Target)*

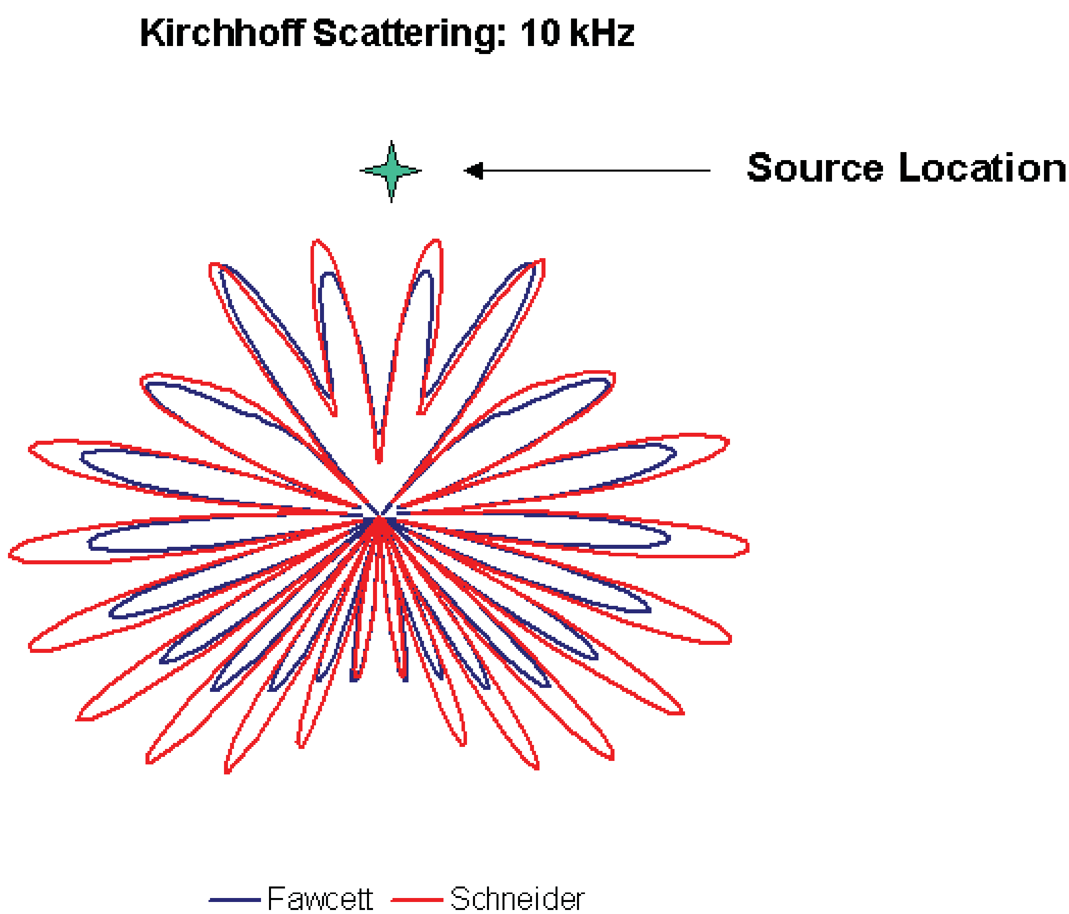

Figure 4.4. *AVAST Kirchhoff Scattering Results at 10 kHz (Full Illumination of Target)*

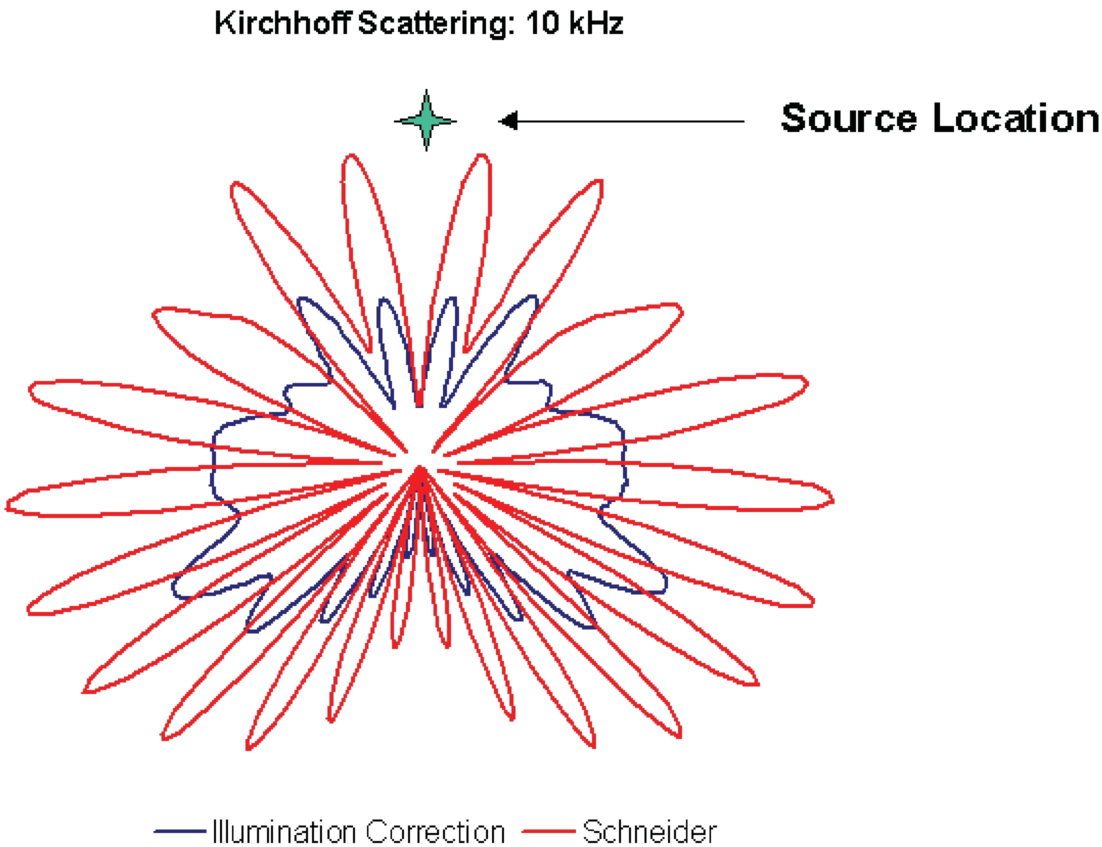

Figure 4.5. *AVAST Kirchhoff Scattering Results at 10 kHz: Full Illumination vs Partial Illumination*

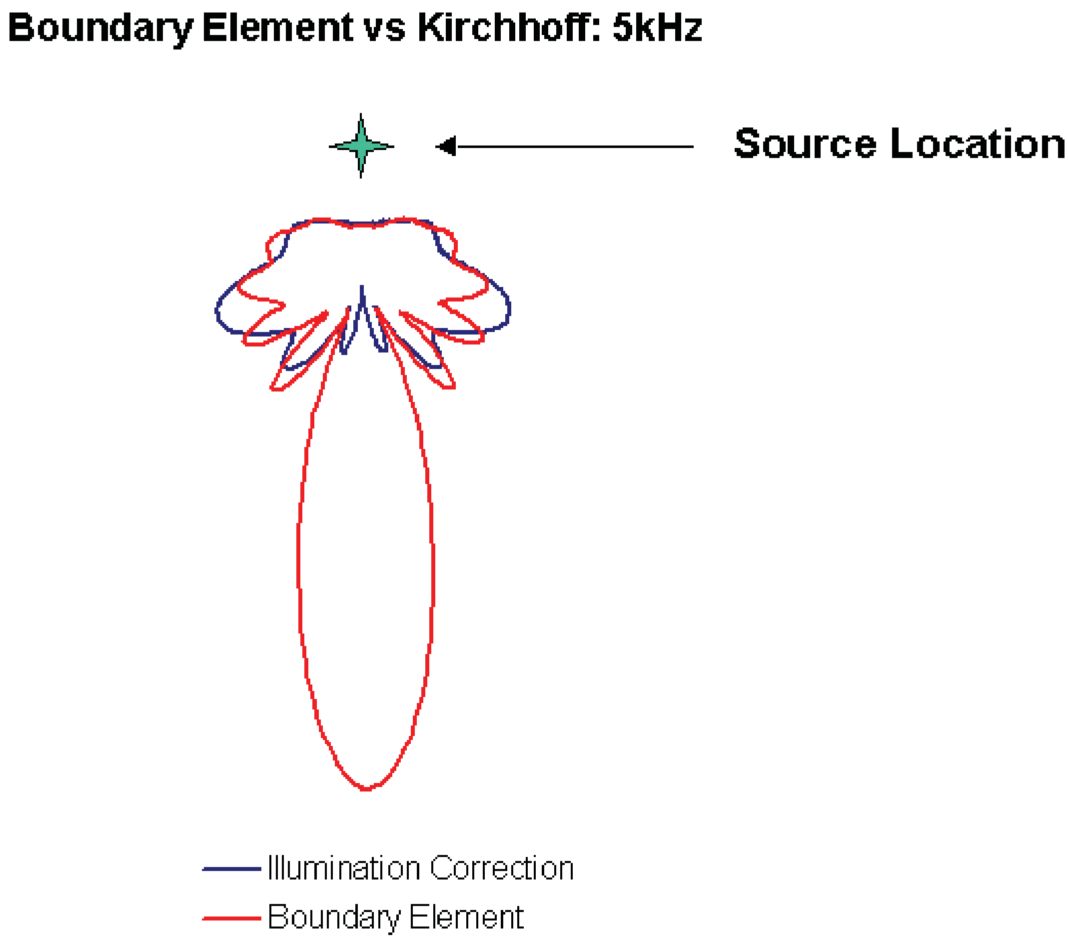

Figure 4.6. *Kirchhoff Scattering (with Illumination Correction) vs Conventional BE Formulation*

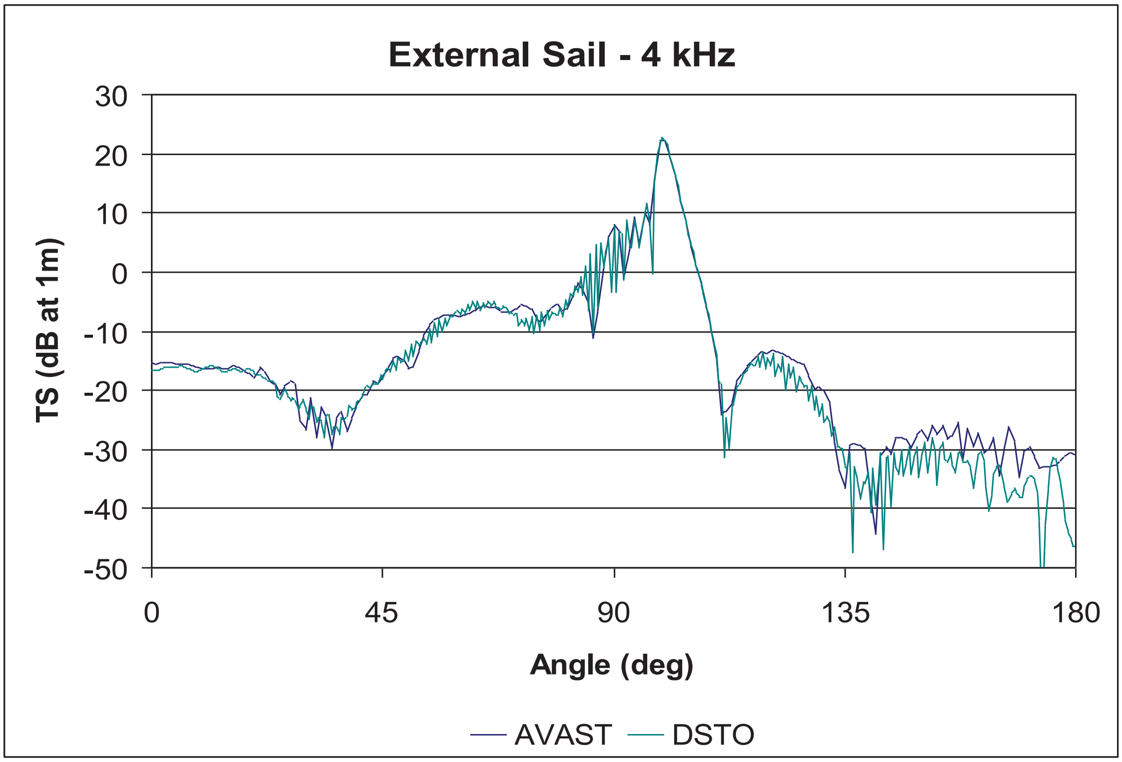

Figure 4.7. *A Comparison of AVAST Kirchhoff and DSTO Results for Submarine Sail at 4 kHz*

5. Perform a Series Target Strength Analysis Using Rigid Cylinder Models Having Impedance Type Boundary Conditions

During the course of the previous software development contract, the AVAST code was upgraded in order to provide user's with a capability for evaluating how various surface treatments impact the target strength of submerged structures. The underlying algorithm developed for use in AVAST required the user to supply impedance boundary conditions, relating pressure to normal velocity, for each boundary element panel on the wet structural surface. As a result, AVAST is then able to generate a system of equations relating surface to incident pressure fields:

$$\left([H] - \frac{i\omega\rho}{z}[G] \right)\{p_s\} = \{p_{inc}\} \tag{5.1}$$

where ω represents the driving frequency (in radians), ρ represents the fluid density, and z represents the surface impedance (i.e.: z = pressure / velocity)

In the discussion which follows, the AVAST surface impedance modelling algorithm will be used to perform a series of impedance-based target strength analyses using cylinder models.

5.1 Model Setup

The model used in this study is based on DRDC Atlantic's acoustic cylinder (see Figure 4.1). For the purposes of this study, the cylinder is assumed to be fully submerged in an infinite fluid having a properties similar to that of sea water (i.e.: density of 1025 kg/m3 and a sound speed of 1500 m/s). For all cases considered, the field points were located 100 m from the cylinder center and positioned on a transverse plane cutting the cylinder mid-way along its longitudinal axis. The acoustic source was positioned at a distance of 1000 m from the cylinder center (oriented at 12 o'clock). For all cases considered in this report, the surface coatings were assumed to be applied uniformly over the entire surface of the cylinder. As a result, a single value of could be used to represent the impedance for all surface panels covering the wet surface.

5.2 Results

In order to evaluate how surface impedance affects cylinder target strength, a series of three trials were conducted. In the first trial, the cylinder was excited at a frequency of 240 Hz (corresponding to a wave number of approximately 1.0). Analyses were conducted using a variety of impedance values ranging from 10^8 to 10^{-3}. The results are summarized in Figures 5.1 – 5.2. In the second set of trials the excitation frequency was increased to 480 Hz (see Figures 5.3 and 5.4). In the final series of trial, the cylinder was again loaded at a frequency of 480 Hz, however for this set of analyses complex values for impedance were used to model the surface impedance conditions (see Figures 5.5 and 5.6).

5.3 Conclusions

It is clear from the results presented in Figures 5.1 – 5.6 that the selection of surface impedance boundary conditions can have a significant impact on the outcome of target strength predictions. For the most part, the target strength predictions follow a predictable pattern: i.e.: as impedance values are increased target strength levels decrease. However some exceptions do exist. For example, a noticeable spike in the forward scatter target strength is evident for the z = 1, 480 Hz case. The reason for this sharp increase is not clear, however one possible explanation could be due to a "resonance", or eigenvalue, associated with the matrix formulation provided above in Equation 5.1 (i.e.: the particular combination of i, ω, ρ and z may be responsible for the ill-conditioning of Equation 5.1).

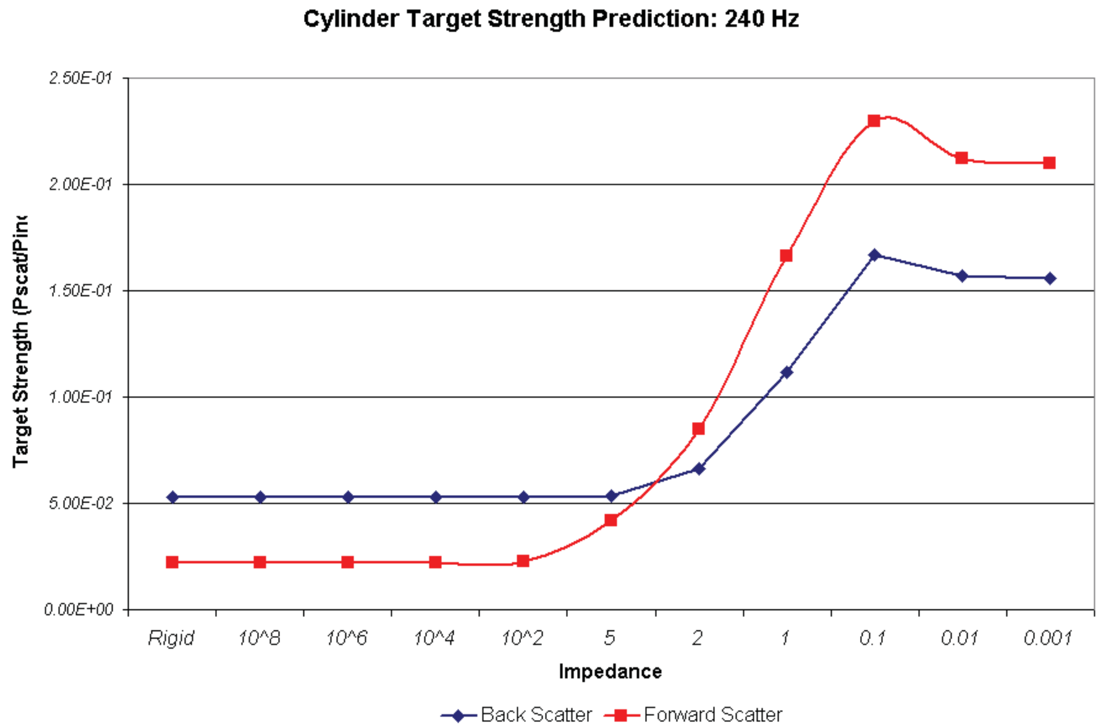

Figure 5.1. *Variation of Forward and Back Scattered Target Strength due to Changes in Impedance (240Hz)*

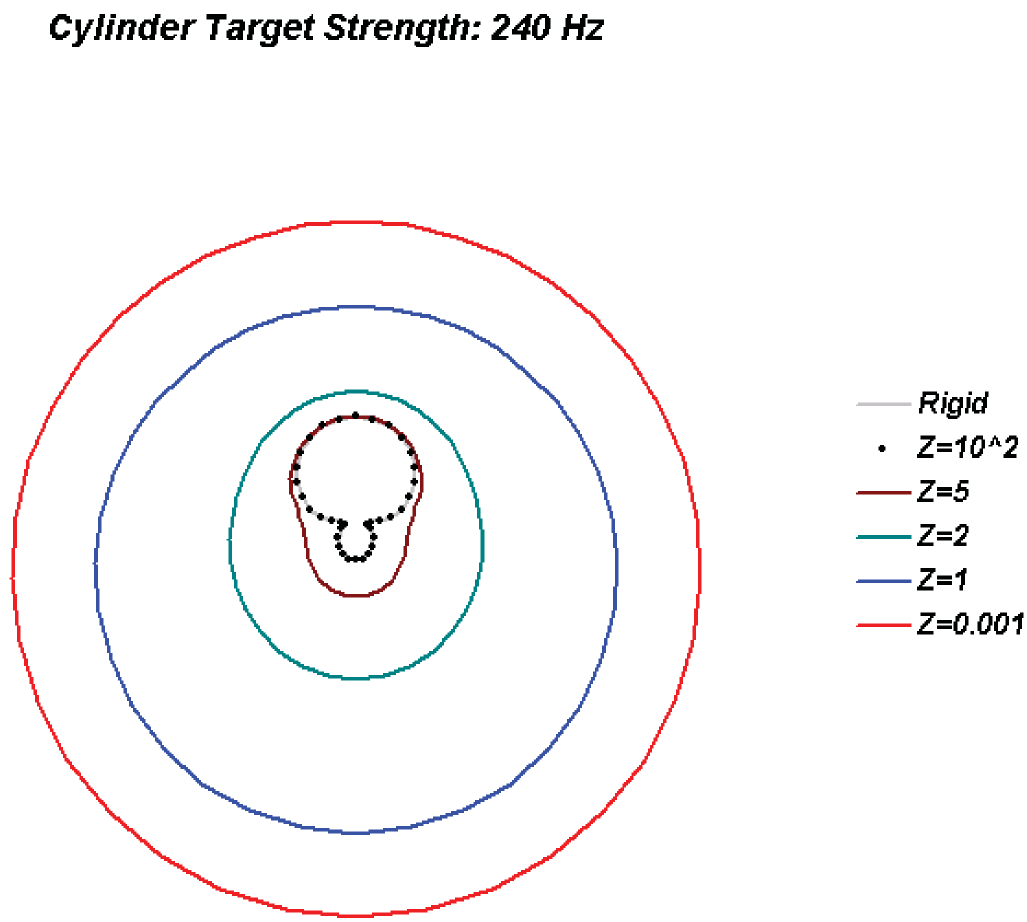

Figure 5.2. *Variation of Target Strength due to Changes in Impedance: Polar Plot (240Hz)*

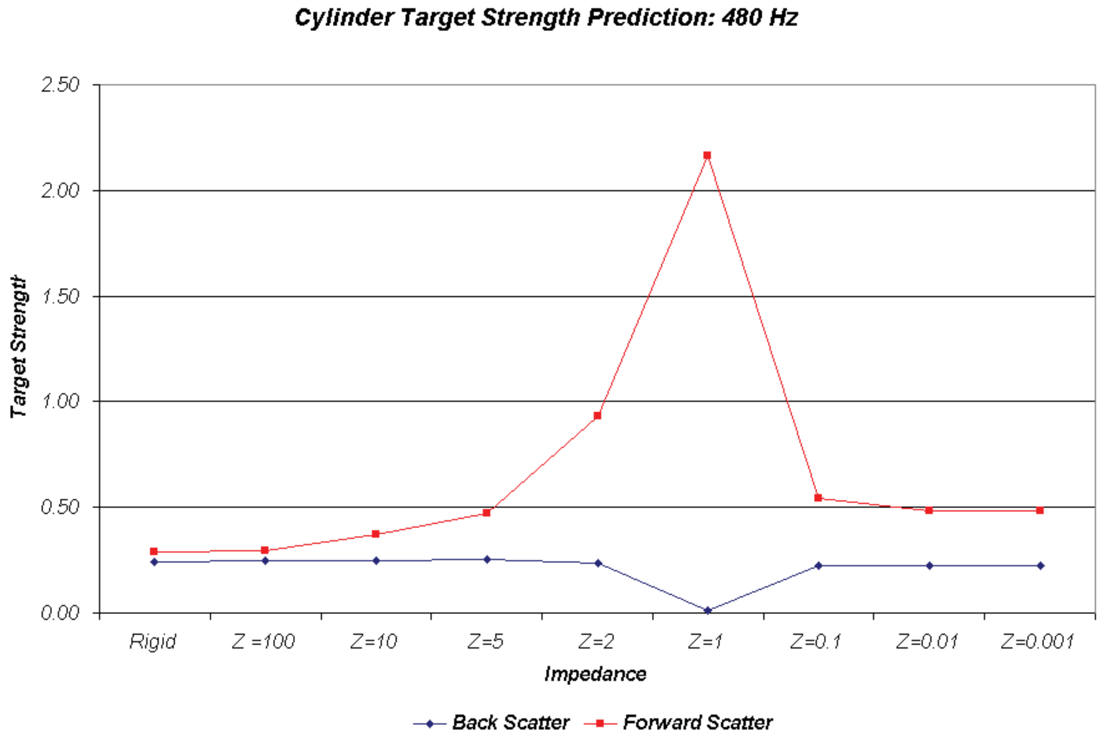

Figure 5.3. *Variation of Forward and Back Scattered Target Strength due to Changes in Impedance (480Hz)*

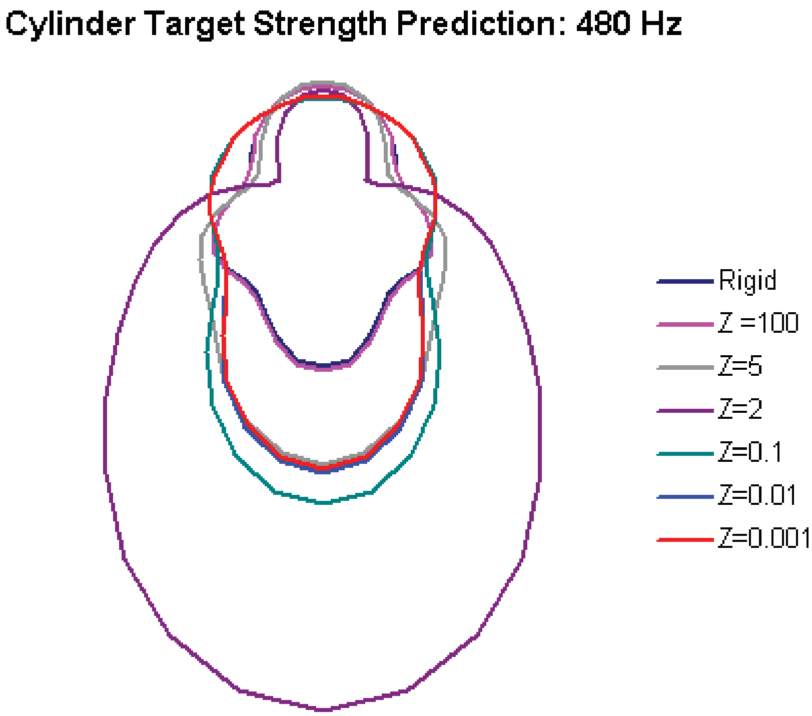

Figure 5.4. *Variation of Target Strength due to Changes in Impedance: Polar Plot (480Hz)*

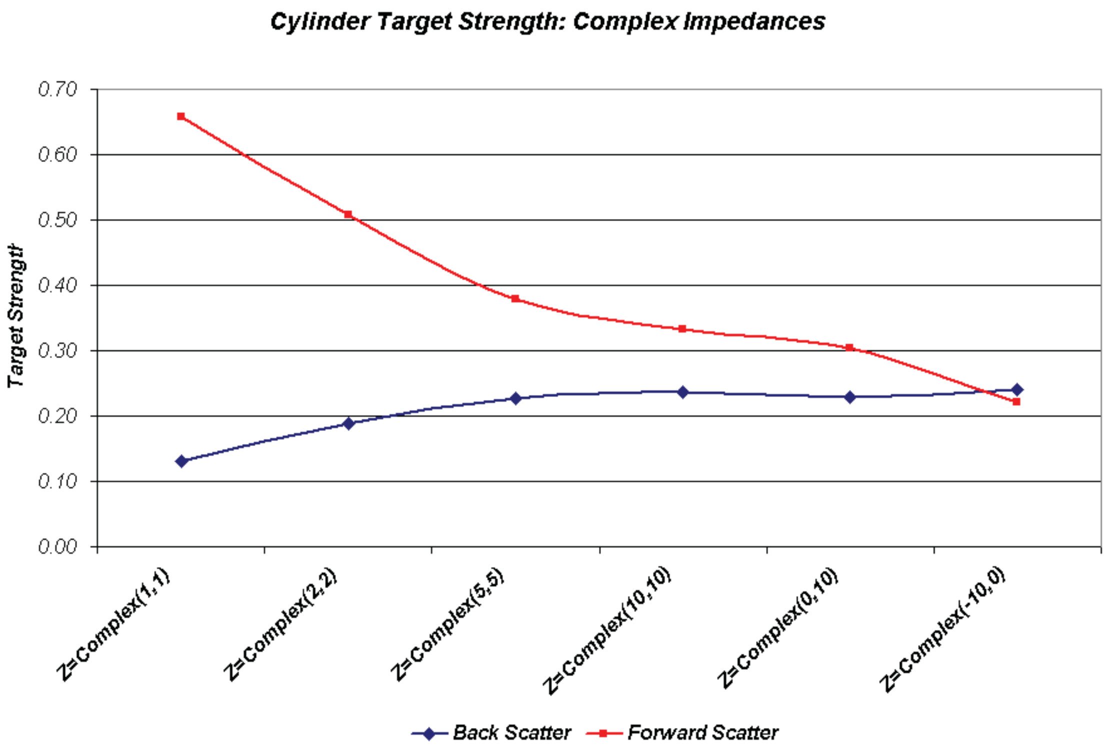

Figure 5.5. *Variation of Forward and Back Scattered Target Strength due to Changes in Complex Impedance (240Hz)*

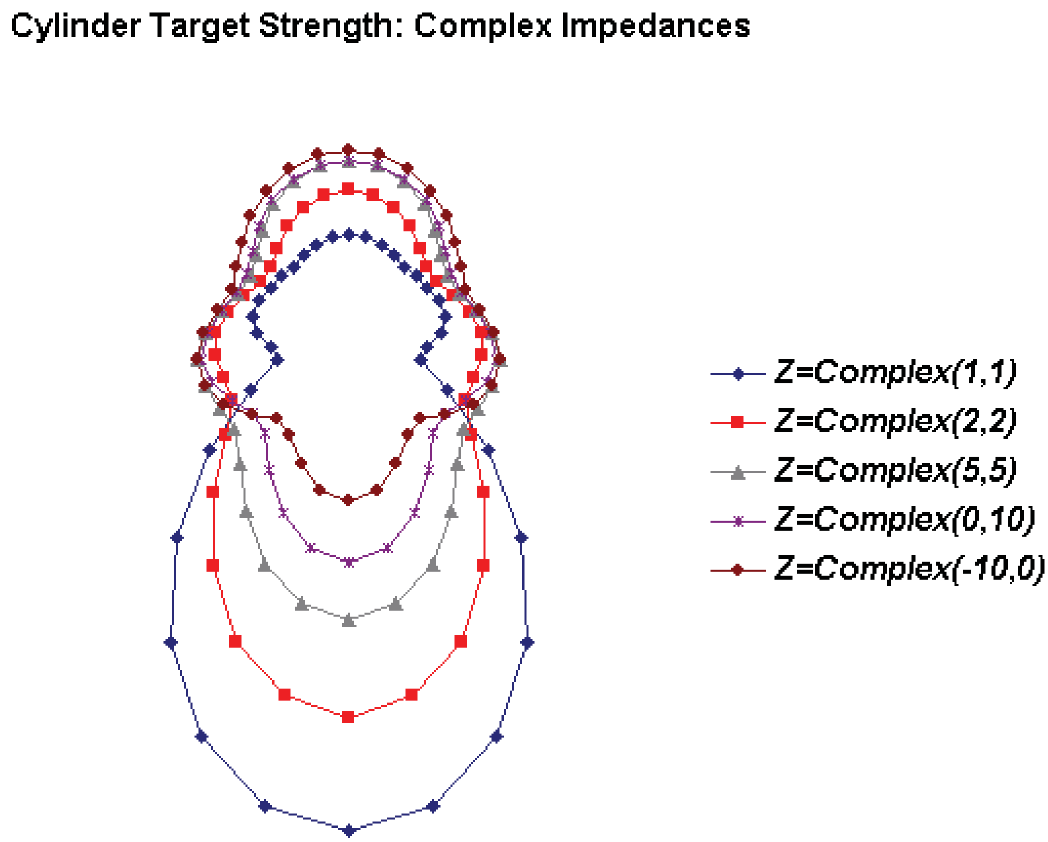

Figure 5.6. *Kirchhoff Scattering (with Illumination Correction) vs Conventional BE Formulation*

6. Review the High Frequency Target Strength Performance of the AVAST Solver

In order to fully exploit the advantages of a parallel computing environment, the AVAST code was completely rewritten over the course of the current software development contract. This allowed the development team to review and re-test the current analysis algorithms that have been at the core of the AVAST software for the past several versions of the code. While this review did not uncover any significant problems with the AVAST code, two sources of potential error were identified: the limitations of the current panel integration routines and the use of the Burton and Miller method to eliminate irregular frequency problems. Details related to both these issues are provided in the discussion below.

6.1 Panel integration routines

In the current version of the AVAST code, Gaussian quadrature is used to compute matrix coefficients related to the Helmholtz equation Green's function and its associated derivative, i.e.:

$$G_{pq} = \int_{S_q} \frac{e^{ikR_{pq}}}{R_{pq}} dS_q$$

$$H_{pq} = \int_{S_q} \frac{\partial}{\partial n_q} \left(\frac{e^{ikR_{pq}}}{R_{pq}} \right) dS_q$$

In general, if a sufficient number of integration points is used, Gaussian quadrature can produce a high degree of accuracy when used for computing the integral equations provided above the equations above. However, in some circumstances (thin bodies for example), quadrature (even high order) may not be able to produce accurate results. In these cases, other integration algorithms, such as the Hess-Smith technique, must be used. The Hess-Smith method is particularly attractive because it uses an analytical formulation to compute the "H" and "G" matrices. Over the course of the current AVAST contract, a version of the Hess-Smith integration method was implemented in an upgraded version of the AVAST solver. While the preliminary results are very encouraging, this version of the Hess-Smith routines are limited to only the constant pressure, three-noded triangular panel. Additional work would be required in order to generalize the method for all panel types currently available in the AVAST fluid element library.

6.2 Burton and Miller Method

It is well known that at certain frequencies (sometimes referred to as irregular frequencies), the exterior Helmholtz integral equation suffers from non-uniqueness. In order to avoid this non-uniqueness problem, AVAST employs the Burton and Miller method. This technique involves generating a linear combination of two forms of the Helmholtz surface integral equation. Unfortunately, in order to generate this combination of equations, high order derivatives of the Helmholtz Green's function (which are expensive to calculate) must be computed.

Due to the significant computational demands related to the Burton and Miller method, it was not regularly used when performing AVAST analysis. However, recent experience gained while performing a series of target strength validation studies using models of both spheres and cylinders, has shown that at high frequencies (where there are a relatively high density of irregular frequencies), it is extremely important to apply the Burton and Miller formulation. In order to illustrate this point, consider the results provided in Figure 6.1 which compare sound pressure levels generated with and without using the Burton and Miller method. Analytical results are also included in order to provide baseline values. Figure 6.1 clearly shows how the results generated using the Burton and Miller method agree much more closely with the analytical results (especially at the irregular frequencies).

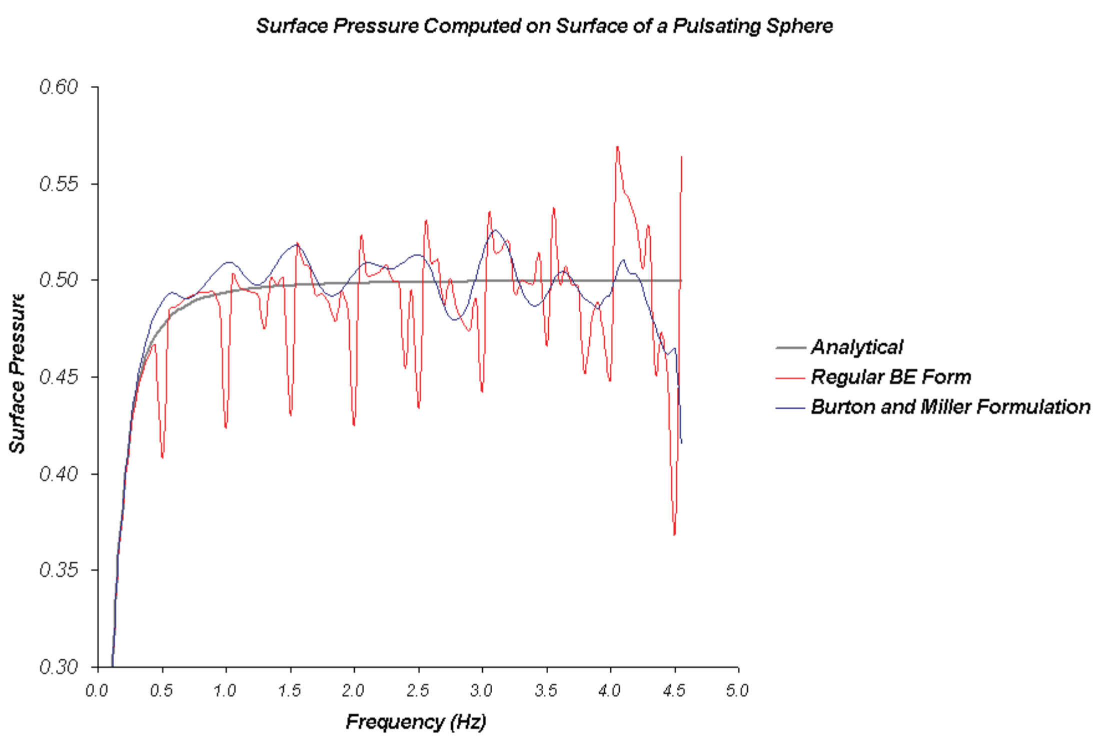

Figure 6.1. *Kirchhoff Scattering (with Illumination Correction) vs Conventional BE Formulation*

7. References

1. J.A. Fawcett, “Modeling of High Frequency Scattering From Objects Using a Hybrid Kirchhoff/Diffraction Approach”, J.A.S.A., 109 (4), April 2001.

2. K.G. Foote, ”Comparing Kirchhoff Approximation and Boundary Element Models for Computing Gadoid Target Strengths”, J.A.S.A., 111 (4), April 2002.

3. H.G. Schneider, et. al., “Acoustic Scattering by a Submarine: Results from a Benchmark Target Strength Simulation Workshop”, Tenth International Congress on Sound and Vibration, Stockholm, Sweden, July, 2003.

4. K.J. Bathe, Finite Element Procedures in Engineering Analysis, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1982

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D.P. Brennan; J.D. Covill
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The development and incorporation of the latest enhancements to the AVAST code are described. The purpose of this work was to make the modeling of the physical environment more realistic, while ensuring that the code runs as efficiently as possible. To this end several new features have been added. These include upgrading the existing library of fluid panels to in order to provide user's with higher order elements better suited for modeling structures with a significant degree of curvature, developing a UNIX version of the AVAST software designed to take full advantage of DRDC's multi-processor SUNFIRE workstation, and the implementation of a high frequency Kirchhoff scattering capability. In addition, a series of parametric studies involving sound scattered from rigid structures having impedance type boundary conditions were also conducted using the latest version of the AVAST solver.

Le présent rapport décrit l'élaboration et l'intégration des dernières améliorations au code AVAST. Le but des présents travaux est de rendre plus réaliste la modélisation de l'environnement physique, tout assurant une exécution aussi efficace que possible du code. Pour ce faire, plusieurs nouvelles fonctionnalités ont été ajoutées, dont la mise à niveau de la bibliothèque actuelle de panneaux de fluides afin de fournir aux utilisateurs des éléments d'ordre supérieur mieux adaptés aux structures de modélisation avec un haut degré de courbure, le développement d'une version UNIX du logiciel AVAST conçue pour tirer pleinement profit du poste de travail multiprocesseur SUNFIRE de RDDC et l'implémentation d'une capacité de diffusion à grande fréquence, fondée sur le modèle de Kirchhoff. De plus, une série d'études paramétriques portant sur des ondes sonores diffusées par des structures rigides présentant des conditions d'impédance aux limites ont également été réalisées au moyen de la version la plus récente du mécanisme de solution AVAST.

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UNIX; AVAST; Kirchhoff; underwater/structural acoustics; finite element method (FEM)