PN-ABZ-897

NATIONAL RESEARCH COUNCIL

OFFICE OF INTERNATIONAL AFFAIRS

2101 Constitution Avenue Washington, D.C. 20418

OFFICE FOR CENTRAL
EUROPE AND EURASIA
Telephone: (202) 334-2644
FAX: (202) 334-2614

OFFICE LOCATION:
The Foundry Building, 2nd Floor
1055 Thomas Jefferson Street, N.W.
CABLE ADDRESS: NARECO

January 10, 1997

U.S. Agency for International Development
Center for Development, Information, Evaluation
1601 North Kent Street
Arlington, VA 22209

To Whom it May Concern:

At the suggestion of John Daly of USAID's Bureau for Global Programs, I am sending the enclosed final reports of projects conducted under the Cooperation in Applied Science and Technology (CAST) program. The CAST program is funded by USAID and administered by the National Academy of Sciences. As I receive additional final reports, I will be sure to forward to you.

If you have any questions regarding the reports or the program, please contact me at 202-334-2644 or <ocee@nas.edu>.

Sincerely,

Sharon Vandivere

Sharon Vandivere
Program Assistant

1

PN-ABZ-897

COOPERATIVE PROJECT
ON
GRID QUALITY AND ADAPTATION APPLICATIONS
FOR
COMPLEX FIELD CONFIGURATIONS

Final Report submitted to

Natalie R. Brand
Program Assistant
National Research Council
Office of International Affairs
The Foundary Building
2nd Floor, 1055 Thomas Jefferson St. NW
Washington, DC 20418

US Investigator: Dr.B.Soni
Engineering Research Center for Computational Field Simulation
Mississippi State University

Visiting Investigator: Dr.O.Ushakova
Institute of Mathematics and Mechanics
Russian Academy of Sciences, Urals Branch
Ekaterinberg, Russia

December 1996

2

TABLE OF CONTENTS

1. Program Participants 3
2. Technical Report 4
3. Benefits and Future Collaborations 12
4. Contribution to CAST Program Goals 13
5. Financial Report 14
6. General Comments 15

1. PROGRAM PARTICIPANTS

US Investigator and Host Institution	Dr. Bharat K. Soni Professor, Department of Aerospace Engineering & Engineering Research Center for Computation Field Simulation Mississippi State University P.O. Box 9627 Mississippi State, MS 39762
Russian Investigator	Dr. Olga Ushakova Institute of Mathematics & Mechanics Russian Academy of Sciences, Urals Branch Ekaterinberg, Russia
Period of Performance	April 1, 1996 – October 15, 1996

Note: Dr. Ushakova left for Ekaterinberg, Russia on October 16, 1996. (Dr. Ushakova visited Russia to attend a conference for 15 days from August 31, 1996 to September 15 1996.)

2. TECHNICAL REPORT

ABSTRACT

The progress realized in the cooperative project on the grid quality and adaptation sponsored by the National Research Council under the CAST program is summarized in this report. Under this project Dr. O. Ushakova of Russian Academy of Sciences (RAS) spent six months working together with Dr. B. Soni and his students at the Engineering Research Center (ERC), Mississippi State University. The variational approach of optimal adaptive grid generation and corresponding software developed by Dr. O. Ushakova in Russia were applied in conjunction with the grid adaptation technology developed by Dr. B. Soni and his group at the ERC. As a result a comprehensive adaptive grid technique combining the best features of grid technology utilized at MSU and a variational method of optimal adaptive grid generation developed in RAS has been created. Computational examples involving two–dimensional grid applications were performed to demonstrate the success of this methodology.

BACKGROUND

The last two decades have seen an increased demand for Computational Field Simulation (CFS) pertinent to fluid dynamics, hydrodynamics, electromagnetism, magnetohydrodynamics, ocean and atmospheric modelling, heat and mass transfer, biomedical and to some degree all physical field problems. CFS involves the numerical solution of a system of non–linear partial differential equations(PDEs) representative of a field being simulated. An essential element of these solutions on general regions is the construction of mesh on which to represent the PDEs in finite form. In general, the construction of such a coordinate mesh (grid) is a formidable task. Grids are subject to many constrains arising from underlying physics, the numerical algorithm or the geometry associated with the regions within which a solution is desired. All these aspects are being taken into account while exploring grid generation algorithms.

The accuracy of the numerical algorithm depends not only on the formal order of approximation but also on the distribution of grid points in the physical domains. For accuracy one has to resolve the local scales so that the variations in the dependent variables are described on so many grid intervals as possible. Generally, it is impractical to use uniformly fine meshes, because of computer memory restrictions and lengthy computation times. Furthermore, such fine meshes are not needed for accuracy in larger parts of the field. The grid employed can have a profound influence on the quality and the convergence rate of the solution. Grid adaptation offers the prospect for accurate field simulations without the use of excessively fine, computationally expensive meshes.

A multitude of techniques utilizing methods of different nature have been developed by researchers at the MSU and the Institute of Mathematics and Mechanics (IMM) of Urals Branch (UB), Russian Academy of Sciences. The methodologies [1–5] developed at MSU are based on the algebraic and elliptic partial differential equations. However, in IMM UB RAS a variational method for generating grids has been originated [6]. The adaptation in both approaches was accomplished by allowing

5

movement of grid points (keeping the number of grid points fixed) and by utilizing grid refinement (increasing the concentration of the grid points in highly varying flow regions). These strategies have been widely applied in Computational Fluid Dynamics. Also, the methods developed by both investigators, Dr. Soni and Dr. Ushakova, are applicable to aerospace, propulsion, nuclear physics and structural applications.

In connection with present investigation, from all distinct methods developed by MSU researchers, it is necessary to single out elliptic method utilizing weight function in conjunction with the equidistribution principle and algebraic technique employing the non–uniform rational B–splines. The principle investigator, Dr. Soni, has developed an adaptive grid technique based on equidistribution principle using elliptic generation. A key ingredient of this technique is the formulation of weight function as a boolean sum of flow field parameters and their variation [4]. Non–uniform rational B–splines (NURBS) technique allows for the description of complex geometry in the parametric form which then can be directly applied in generating grids. The parametric definition by NURBS can also be utilized to generate adaptive grids [5].

The visiting investigator Dr. Ushakova has elaborated the adaptive grid generation method [6–8] within the approach developed at the IMM UB RAS. This method is based on variational principle. Here the grid generation is carried out by minimizing the grid quality functional. This function is defined by evaluating the sum of the grid measures. These grid measures are formalized as: (i) the closeness of a curvilinear grid to the uniform one, (ii) the orthogonality requirement and (iii) adaptation criteria. The main feature of this method, [6] which makes it different from the others, lies in the special way of formulation of the criteria of uniformity mentioned above. This formulation defines the types of the system of Euler equations arising in minimizing the variational grid quality functional and permits the consideration of different types of boundary conditions in the variational problem of grid generation. This formulation has been validated in view of the quality of grids obtained.

OBJECTIVES

Dr. Ushakova and Dr. Soni worked together with graduate students to accomplish the following objectives:

- Develop a comprehensive adaptive grid technique by combining the best features of MSU adaptive grid codes and the software developed by Dr.Ushakova.
- Apply grid adaptation codes to real world configurations involving field simulation problems of practical interest.

ACCOMPLISHMENTS

The concentration is in satisfying the following criteria during the development associated with this collaborative effort.

- Universality. The grid generation algorithm should make it possible to compute grids for a large class of domains of complex forms.
- Cost–effectiveness of algorithm. It is necessary that the computational cost of constructing high quality grids raising the accuracy of computation of the differential problem with a relatively small number of nodes should not exceed the total cost of solving the problem with the same accuracy by using some standard low–quality grids but with a large number of nodes.
- Reliability of algorithms. It is necessary to prescribe an exact choice of control parameters (weight functions, weight parameters, etc.) in the algorithms and programs to be used which would ensure an automatic failure–free construction of grids for a given class of domains and adaptation conditions.
- Minimal information to be used. It is desirable in constructing grids to give data concerning only the form of the domain boundaries and the number of grid nodes in each coordinate direction.

Dr.Ushakova began her work at ERC with studying the computing platform. She became acquainted with different software environments available on Sun SPARC workstation and higher performance graphics workstation (SGI–IRIS). The grid generation and adaptive softwares were used to understand the underlying algorithms.

Dr.Ushakova studied the grid adaptation approach applied at ERC. The algebraic approach represented by NURBS tools developed at ERC allows, in the most efficient way, description of a complex geometry configuration and obtainment of an explicit algebraic transformation of the unit square (in two–dimensional case) or cube (in three–dimensional case) into a physical field domain, resulting in a curvilinear grid in the described domain. The transformation obtained allows generation of an adaptive grid in the physical domain by employing an adaptation in the auxiliary domain which is a square or a cube.

Dr.Ushakova applied her method for generating grids to different cases involving adaptive solution function. Software elaborated by her allowed her to get efficient, good quality grids. This is demonstrated in figures 1b–c. The grid generated using variational technique is displayed in fig.1c. The grid displayed in figure 1.b is obtained by the weight function method [4]. The approach which has been taken to utilize the best features of these algorithms is outlined in the following discussion.

- Describe the geometrical components using NURBS.
- Apply variational technique of grid adaptation in the parametric space (unit square [0,1]x[0,1] in two dimensions).
- Generate adaptive grid in the physical space by evaluating the underlying NURBS geometry at adapted parametric distribution.

The results of this procedure for different configurations are presented in figures 2,3. The physical space is demonstrated in figures 2b, 3b. The adapted parametric space is displayed in Fig. 2a,3a.

To realize such technique utilizing the variational method, [8] a special algorithm of the movement of boundary grid nodes as well as a special algorithm of interpolation of the solution has been developed. This modification has been made within the possibilities, guaranteeing by the form of the vari-

ational grid quality functional admitting different types of boundary conditions. The elaborated algorithm preserves the values of angles between coordinate lines and the boundary during iterations allowing the boundary nodes to move. This has been demonstrated on the fig.1c,d. Such modification of the variational method permits the obtainment of a final grid (fig.1d) with the same slope of the coordinate lines with which it was obtained by NURBS technique at first as an initial grid (fig.1c) for iterative procedure. This feature of the variational algorithm turns out to be essential for the case when coordinate lines are orthogonal to the boundary. Combined technique has been applied for different configuration of the domain and for different examples of the solution function under which adaptation has been done. The estimates of grid quality have been carried out for all considered cases.

Collaborative efforts were mutually beneficial to both the United States and Russia.

RESULTS

A comprehensive adaptive grid generation technique combining the best features of MSU, ERC grid codes, and UB RAS software has been developed. This technology involves algebraic (NURBS) approach, weight function approach originated in MSU, and variational approach developed in Russia.

This collaborative technology has been applied to two–dimensional complex configuration. The grid quality of resulting adaptive grids has been estimated and found to be acceptable for real Complex Field Simulation.

The directions of future collaborations involving extension of this technology to three dimensions have been planned.

FUTURE COLLABORATIONS

The aforementioned investigations have been implemented in two dimensions. The resulting collaborative technique is proven to be efficient to address the complex configurations. This provides the motivation for extending described technology to three dimensions.

ACKNOWLEDGMENTS

Both investigators Dr.Soni and Dr.Ushakova appreciate NSF for financial support of such research. Dr.Ushakova appreciates her co–investigator Dr.Soni and all graduate students of his group for their kind and friendly attitude towards her .

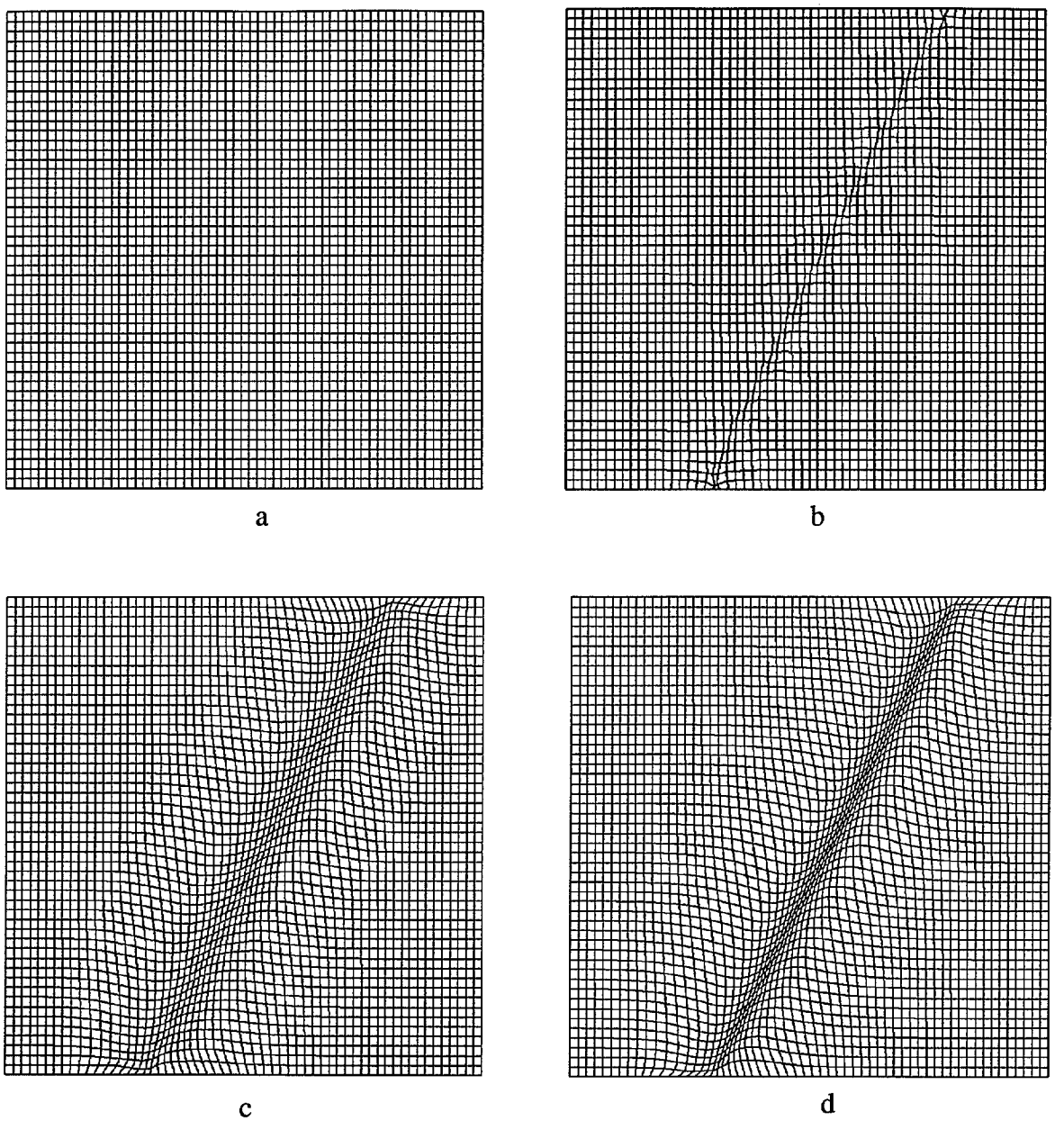
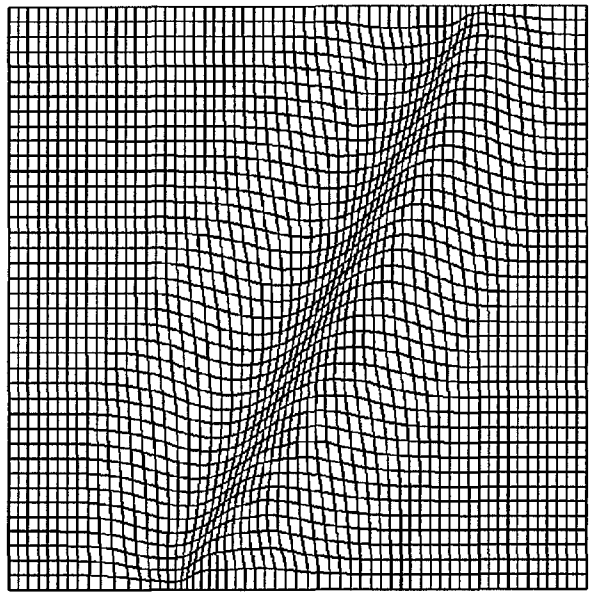


Fig.1. Adaptive grids in the unit square for function

$$z = \begin{cases} 1, & 2x - 0.6 - y \geq 0 \\ 10, & 2x - 0.6 - y < 0 \end{cases}$$

a – initial grid
b – weight function method
c – variational method, fixed boundary nodes
d – variational method, fixed boundary angles

a



b

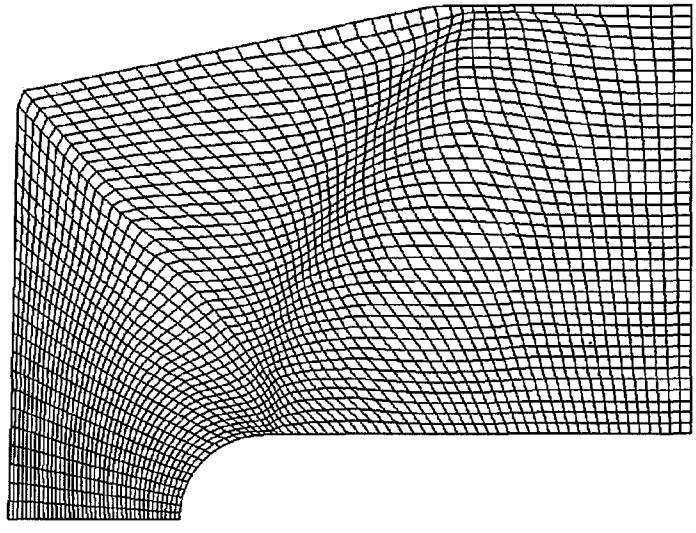


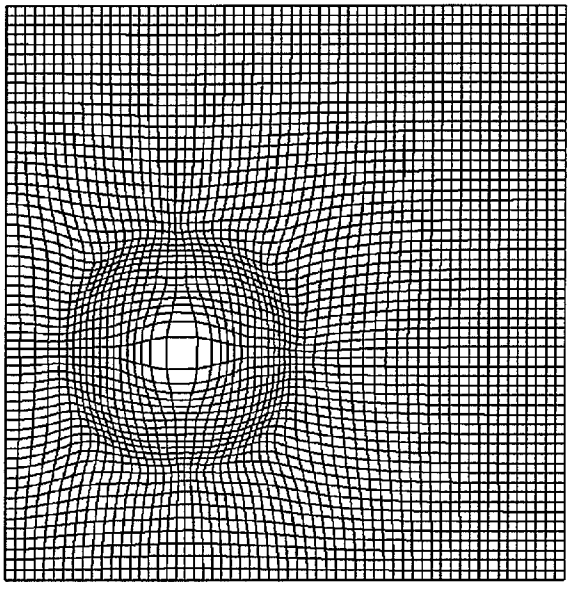
Fig.2. Adaptive grids ,
variational method,
fixed boundary angles,
function in unit square :

$$z = \begin{cases} 1, & 2x - 0.6 - y \geq 0 \\ 10, & 2x - 0.6 - y < 0 \end{cases}$$

a – unit square
b – physical space

10

a



b

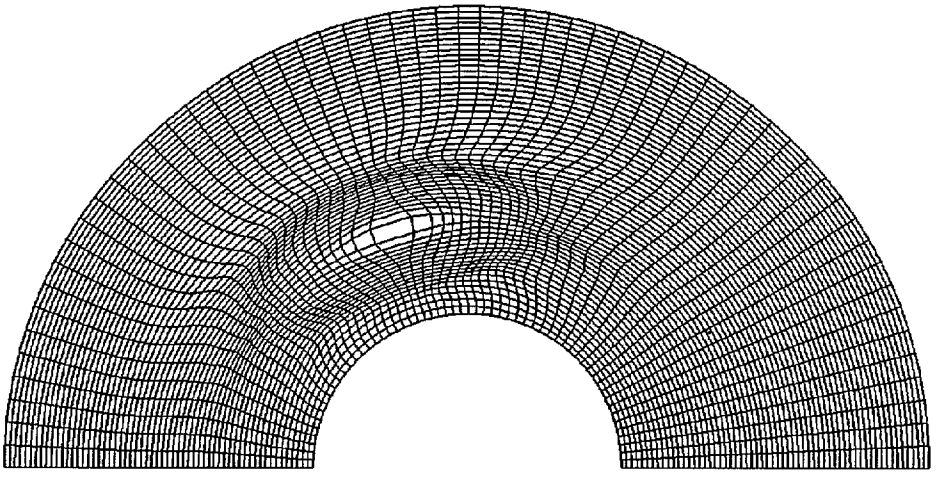


Fig.3. Adaptive grids ,
variational method,
fixed boundary angles,
function in unit square :

$$z = \begin{cases} \exp\left(-\dfrac{((x-a)^2 + (y-b)^2 - r^2))}{\epsilon}\right), & (x-a)^2 + (y-b)^2 > r^2 \\ \dfrac{-((x-a)^2 + (y-b)^2 - r^2)}{\epsilon} + 1, & (x-a)^2 + (y-b)^2 \le r^2 \end{cases}$$

$a = 0.31$, $b = 0.4$, $\epsilon = 0.001$

a – unit square
b – physical space

REFERENCES

[1] SONI, B.K., WEATHERHILL, N.P., and THOMPSON, J.F., "Grid Adaptive Strategies in CFD", Advanced in Hydro–Science and Engineering, University of Mississippi Press, Wang, S.S.Y.(ed.), 1.A:201–208.

[2] SONI,B.K., and YANG, JIANG., " General Purpose Adaptive Grid System", AIAA–92–0664, AIAA 30th Aerospace Science Meeting, Reno, NV., January 1992.

[3] SONI, B., *"Grid Generation: Algebraic and Parttial Differential Equations Techniques Revisited, "* Computational Fluid Dynamics'92, Hirsch, Periaux and Kordulla, (eds.), Vol.2, pp.929–936, September, 1992.

[4] THORNBURG, H.J., and SONI, B.K., "Weight Functions in Grid Adaptation", 4th International Conference on Numerical Grid Generation in Computational Fluid Dynamics and Related Fields, Swansea, U.K., April, 1994.

[5] YU, T.–Y., and SONI, B.,"Application of NURBS in Grid Generation," Computer–Aided Design, Vol.27, No.2, pp.147–157,1995.

[6] SEREZHNIKOVA, T.I., SIDOROV, A.F. and USHAKOVA, O.V., "On One Method of Construction of Optimal Curvilinear Grids and Its Applications", Sov.J.Numer.Anal.Math.Modelling, Vol.4, No.2, pp.137–155 (1989)

[7] USHAKOVA, O.V., "LADA – Efficient Algorithm and Program of Generation of Two–dimensional curvilinear Grids in Simply–connected Complex Geometry Domains, Voprosy Atomnoy Nauki i Tekhniki. Ser.: Matem. Modelirovanya Fizicheskikh Processov, 1994, No.3., pp.47–56.

[8] USHAKOVA, O.V., "Algorithm of Two–Dimensional Adaptive Grid Generation", Numerical Grid Generation in Computational Field Simulations. Proceedings of the 5 th International Conference, held at Mississippi State University, April 1 –April 5, 1996, pp.37–47.

12

3. BENEFITS AND FUTURE COLLABORATION

Dr. Olga Ushakova provided an indepth mathematical foundation on variational methods for grid generation and grid adaptation. This approach is mathematically sound. However, its extension to full three dimensional configurations involving complex geometry is extremely tedious and not practical. The approach taken in the US for practical industrial applications involves algebraic techniques and methods based on solving nonlinear partial differential equations. Dr. Ushakova spent the first two months learning the MSU/ERC UNIX based computing environment and two months in understanding the MSU/ERC approach in grid generation. A collaborative effort was taken to blend the best features of both methods to accomplish grid adaptation. This work was done for two dimensional configurations. A collaborative proposal to extend and blend the best features of Dr. Ushakova's approach and MSU/ERC's approach for full three dimensional complex configurations is being developed.

B

4. CONTRIBUTION TO CAST PROGRAM GOALS

- The US technology for grid adaptation is needed for full three dimensional complex geometries. The research background of Dr. Ushakova and their approach does not offer any short term payoff. However, there is a potential to blend the variational approach utilized by them with MSU/ ERC techniques.
- A collaborative relationship has been established. Also, Dr. Soni, the US investigator was asked as the invited speaker for the grid generation conference in Russia. Various research links have been established due to this visit and collaboration.
- The Urals branch of the Russian Academy of Science has been traditionally working in the area of nuclear physics related mathematical problems. The applications involving environment and ocean modeling problems were explored during this visit.
- The potential for commercial application of the work performed is nil.

5. FINANCIAL REPORT

Stipend	$6,000.00
Insurance	398.00
Travel/Conference Reimbursement	4,555.98
Software	178.00
ID Card	10.00
Supplies	640.51
TOTAL EXPENDITURES	$11,782.49

6. GENERAL COMMENTS

The NRC programs to establish collaborations with Russian scientists plays a vital role in the Research and Development community in Russia. The scientific and mathematical theoretical foundation of Russian scientists is very sound. However, their exposure to the state–of–the–art high performance computing environment does not exist.

CAST FINAL REPORT FOR NUNE S. DARBINIAN (VISITING SCIENTIST) AND STANTON B. GELVIN (SPONSORING SCIENTIST) DECEMBER 10, 1996

1. **Sponsoring Scientist and Institutional Affiliation:** Dr. Stanton B. Gelvin, Department of Biological Sciences, Purdue University, West Lafayette, IN 47907

   Visiting Scientist, Country of Origin, and Institutional Affiliation: Dr. Nune Darbinian, Republic of Armenia; Institute of Molecular Genetics, Moscow, Russia

   Inclusive Dates of Visit: February 1, 1994-June 30, 1996 (CAST supported Dr. Darbinian January 1, 1996-December 31, 1996)

   Current Location of Visiting Scientist: Dr. Darbinian is currently in Dr. Gelvin's laboratory at Purdue University, where she will remain until June 30, 1996

2. Scientific Objectives and Research Performed:

During the time in which CAST supported Dr. Darbinian, she continued her work to develop a novel genetic transformation system of plants. This work involved the *in vitro* synthesis of "artificial T-strands", the introduction of these molecules into tobacco protoplast cultures, the regeneration of antibiotic- or herbicide-resistant calli, and the molecular characterization of these transformed cells.

The "artificial T-strand" concept is derived from the presumed molecular mechanism by which *Agrobacterium tumefaciens* transfers DNA to and genetically transforms plant cells. To effect this transformation, the bacterium processes a portion of a resident plasmid (the Ti-, or tumor inducing, plasmid). The processed portion of this plasmid, the T-(or transferred) DNA, is transferred to plant cells in a manner similar to that of bacterial conjugation. The T-DNA is processed from the Ti-plasmid by the action of an endonuclease, the product of the *virD2* locus. VirD2 protein nicks the Ti-plasmid at two directly repeated sequences (the T-DNA borders) that flank the T-DNA and covalently attaches to the 5' end of the resulting single-stranded DNA (the T-strand). It is this VirD2/T-strand complex that is thought to be transferred to plant cells. VirD2 protein contains nuclear localization sequences (NLS) that presumably target this complex to the plant cell nucleus. VirD2 protein is likely involved in integrating the T-strand DNA into the plant chromosomes.

Agrobacterium-mediated T-DNA transfer is the most commonly used mechanism to genetically transform plant cells. Transgenic plants derived from this mechanism of transformation generally have one or a very few copies of T-DNA integrated into the plant genome. The integration pattern is usually simple; massive rearrangements or catenation of the T-DNA is not common. This simple pattern of DNA integration is favored by plant molecular biologists and biotechnologists. However, there is currently an important limitation to the use of *Agrobacterium* for the genetic modification of plants: Many of the most agronomically important crops, including maize, wheat, and soybean, are highly recalcitrant to *Agrobacterium*-mediated transformation. To genetically transform these crops, scientists usually employ *in vitro* methods of gene introduction, including electroporation and particle bombardment (the "gene gun"). These latter methods are generally inefficient (the frequency of transformation is low) and usually a high copy number of rearranged, catenated DNA molecules is integrated into the plant genome. Thus, whereas these *in vitro* techniques are relatively host range-independent, the quality of the integration event is less than desirable.

The "artificial T-strand" concept attempts to incorporate the best attributes of both *Agrobacterium*-mediated transformation (the relatively simple pattern of T-DNA integration) and *in vitro* transformation technologies (the relative lack of species host-range limitations). "Artificial T-strands" are generated by the *in vitro* cleavage of single-stranded DNA containing T-DNA borders by purified VirD2 protein that has been overproduced *in*

E. coli. With Dr. Darbinian's help, we have been able to generate tens of microgram quantities of these molecules *in vitro*. The technology developed to do this involved cloning various genes (encoding kanamycin- or phosphinothricin-resistance, or the jellyfish green fluorescent protein) between T-DNA borders, then using a combination of standard two-directional PCR and one-directional PCR to generate single-stranded molecules that are subsequently cut by VirD2 protein *in vitro*. Dr. Darbinian performed the cloning experiments, then went on to introduce these VirD2/T-DNA complexes into tobacco protoplasts by electroporation. She developed efficient electroporation conditions, and has now generated both kanamycin-resistant and phosphinothricin-resistant calli. As controls, she has electroporated both double- and single-stranded DNA (not cut by VirD2) into tobacco protoplasts and generated antibiotic- and herbicide-resistant calli. These calli are currently growing and will soon be large enough to analyze for the integration pattern of DNA into the tobacco genome. Nune will use a combination of DNA blot and PCR analyses to define the integration pattern of the foreign DNA.

3. Benefits to Sponsor and Visiting Scientist:

The benefits to Dr. Darbinian are numerous, including the opportunity to perform plant molecular biology/biotechnology research in an environment not available in her home institution, training in protein over-expression and purification (VirD2 protein), and training in electroporation and tissue culture techniques. She should be able to take this knowledge back to Moscow and help set up similar experiments there. Regarding the benefits to the sponsor, Dr. Darbinian has become the laboratory expert in protoplast isolation, electroporation, and tissue regeneration. She has taught numerous people, both in this laboratory and in other laboratories on the floor, these techniques.

4. Future Collaboration and Research Program Extension:

Dr. Darbinian is the fifth scientist that has worked in Dr. Gelvin's laboratory from Dr. Eleonora Piruzian's laboratory (Institute of Molecular Genetics, Moscow). I expect to continue contacts with Dr. Piruzian in the future. In addition, we have just been awarded a two-year North Central Biotechnology Program grant to continue this research.

5. Contributions to CAST program goals:

A. Benefits to the NIS and to the U.S.: Should this novel technology prove effective, it should help in the genetic modification of crop plants.

B. Improving scientific and cultural linkages: As mentioned above, Dr. Darbinian is one of many visiting scientists from the Institute of Molecular Genetics (Moscow) in my laboratory. In addition to Dr. Darbinian, one other scientist from this institute is currently in my laboratory. I expect that in the future there will be continued collaboration between my laboratory and that of Dr. Piruzian.

C. Defense conversion: Not applicable

D. Commercial application: Should this technology be effective, it would immediately be licensed by several agricultural biotechnology companies. Several of these companies are co-sponsoring this research.

6. Financial Report: A more detailed financial report is appended. Dr. Darbinian's salary was supplemented by DOE funds from a grant from the Consortium for Plant Biotechnology Research. Her total annual salary (not including benefits) is $21,000.

Estimated monthly expenses: Rent: $550 (includes utilities, telephone, cable)
Food: $300
Transportation: $40 (bus fare)

In addition, Dr. Darbinian attended and presented a talk at the 17th Annual Crown Gall meeting (Champaign/Urbana, IL). The cost of registration, transportation, food, and hotel was approximately $100.

7. Additional comments: We wish to thank the National Research Council for the opportunity to have Dr. Darbinian work in Dr. Gelvin's laboratory. The CAST grant made it considerably easier for this cooperation to take place. Dr. Gelvin would appreciate receiving literature in the future regarding continuation of this program, and whether there are similar programs for international cooperation with other countries. Finally, Dr. Gelvin would like to see any summaries that the NRC has on how many people were funded by CAST, and where these people are now.

CAAC066O

BS

DEPARTMENTAL FINANCIAL SUMMARY STATUS REPORT AS OF 10/31/96

FUND 550 CENTER 1392-0851

NATIONAL RESEARCH COUNCIL PROJECT PERIOD: 01/01/96 - 12/31/96

GROUP NO.	DESCRIPTION 12L	TOTAL AWARD	THIS MONTH EXP/INC	ACC TO DATE EXP/INC	UNEXPENDED BALANCE	ENCUMBRANCE	UNENCUMBERED BALANCE	COMMITMENTS	TOTAL AVAILABLE
	COMPENSATION								
7-8210	PROFESSIONAL PERS	10,310.00	875.00	8,708.34	1,601.66		1,601.66		1,601.66
	SUB-TOTAL SALARIES	10,310.00	875.00	8,708.34	1,601.66		1,601.66		1,601.66
7-8280	FRINGE BENEFITS	1,690.00	14.03	995.80	694.20		694.20		694.20
7-8200	TOTAL COMPENSATION	12,000.00	889.03	9,704.14	2,295.86		2,295.86		2,295.86
	SUPPLIES & EXPENSE								
7-8431	TRAVEL-FOREIGN	1,800.00			1,800.00		1,800.00		1,800.00
7-8499	OTHER S&E	1,200.00			1,200.00		1,200.00		1,200.00
7-8400	TOTAL S&E	3,000.00			3,000.00		3,000.00		3,000.00
	TOTAL DIRECT	15,000.00	889.03	9,704.14	5,295.86		5,295.86		5,295.86
	TOTAL COST	15,000.00	889.03	9,704.14	5,295.86		5,295.86		5,295.86
	TOTAL SPONSOR COST	15,000.00	889.03	9,704.14	5,295.86		5,295.86		5,295.86
6-4199	INCOME	15,000.00		14,000.00	1,000.00		1,000.00		1,000.00

1-1101: $4,295.86

```
*  *  *  *
```

Report On CAST Visitor at Rensselaer Polytechnic Institute

November 25, 1996

1. This report is prepared by Julian D. Cole, Professor of Applied Mathematics at Rensselaer Polytechnic Institute, in Troy, NY 12180-3590. The report covers the visit of Dr. Eugene Terent'ev from Russia where he is a member of the Computing Center of the Russian Academy of Sciences, Moscow. The visit covered the period October 1995 to July 1996. Dr. Terent'ev has returned to Moscow.

2. The specific problem under study was the stability of three dimensional boundary layers, as typically occur, for example, on the swept-back wings of airplanes. The work was carried in cooperation with J.D. Cole and O.S. Ryzhov of RPI.

The problem for a thin near-wall region is reduced, within the triple-deck approach to unsteady three dimensional nonlinear boundary-layer equations subject to an interaction law. A linear version of the boundary-value problem describes eigenmodes of different nature (including crossflow vortices) coupled together. The frequency ω of the eigenmodes is connected with the k and m of the wavenumber vector through a dispersion relation. This relation exhibits two singular properties. One of them is of basic importance since it makes the imaginary part $Im(\omega)$ of the frequency increase without bound as k and m tend to infinity along some curves in the real (k, m) plane. The singularity turns out to be so strong that the initial value problem is ill posed.

Accounting for the second-order approximation in asymptotic expansions for the upper and main decks brings about significant alterations in the interaction law. A new mathematical model uses a set of composite equations without rescaling the original independent variables and desired functions. As a result the right-hand side of a modified dispersion relation involves an additional term multiplied by a small parameter $\varepsilon = R^{-1/8}$, R being the reference Reynolds number. The aforementioned strong singularity is missing from the solutions of the modified dispersion relation. Thus, the range of validity of a linear approximation is extended in ω, k and m, but the incorporation of the higher-order term into the interaction law means in essence that the Reynolds number is retained in the formulation of a key problem for the lower deck.

The simplest receptivity problem on a vibrating ribbon is posed to simulate real experimental set-ups used at present in wind-tunnel tests. Careful investigation of a solution to this problem points to absolute (rather than convective) instability of any 3D boundary layers involving crossflow. Wave packets of two different types can be generated by the ribbon when operating in the pulse mode. The most rapidly growing signal sweeps downstream. However, there exists one more highly modulated disturbance propagating upstream. It is because of their exponential amplification that such disturbances give rise to earlier transition to turbulence known from experiments with swept-wing boundary-layers. Once the boundary layer on a swept-wing is slightly disturbed, it proves to be incapable of recovering its initial stage.

A paper, "A Composite Asymptotic Model for the Wave Motion in a Steady Three-Dimensional Subsonic Boundary Layer" by O.S. Ryzhov & E.D. Terent'ev, with derivation of an extended version of the triple-deck theory is submitted to the Journal of Fluid Mechanics.

21

3. The benefits of this research to our group was a deeper understanding of the mechanisms of instability in three-dimensional boundary layers. Also, we became familiar with the asymptotic techniques of the Russian researchers.

4. We expect this work on stability of three-dimensional boundary layers to continue and we expect to maintain contact with Dr. Terent'ev.

5. The benefits to Russia and the United States of this visit lie mainly in the renewing of personal contacts in addition to the joint research conducted. The people at the Computer Center are now aware of the work of our group. We have various contacts in the Computer Center. Commercial application possibly lies in the future when a better understanding of stability and transition to turbulence will allow possible methods of control to be used.

7. Financial Report

B10222 National Research Council

Eugene Terentiev

Participant Support	$10,670
Travel Support	$1,328.95
Total	$11,998.95

22