TESTING GUIDELINES FOR NPARC ALLIANCE SOFTWARE DEVELOPMENT[i]

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1.0 Introduction

This document provides testing guidelines for NPARC Alliance software development efforts. It is tailored to the code resulting from the NPARC/NXAIR code merger effort, but with some modifications, could be applicable to other software development projects. It is intended to be used in the development phase of the code, and provides guidelines for evaluating the following:

- Overall functionality of the software

- Functionality of specific features of the software

The test cases described in this document are intended to be run in a relatively simple and quick manner, as much as each flow case permits. They are not intended to provide an in-depth and highly detailed validation of the code. (Detailed validation will most likely occur at a later stage in the code development and will be modeled after the "NPARC Validation Standards" included in the Appendix.) Each test case will be documented and archived so that users/developers will have access to input/output files, plotted results, and other pertinent information. Wherever possible, the computed results for each test case should be compared with experimental data and/or a solution computed with another flow solver.

2.0 Testing Overall Software Functionality

In this document, the "functionality" refers both to the mechanical aspects of the software, i.e. it's ability to compile, run and produce the desired output, and to the software's ability to compute the correct flow physics. The following cases are to be used for testing overall functionality:

- Laminar flat plate

- Turbulent flat plate

- Driven cavity

- Wing/airfoil

- Shock tube

- Simple combustion

2.1 Procedure

When a developer makes changes to the code, the overall code functionality must be evaluated before the changes are incorporated into the controlled version of the software. The procedure for evaluating the code's functionality is described below.

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i. This is draft 0.3 of this document, released, April 16, 1997.

- Choose at least 1 test case (whatever seems most appropriate). It is left to the developer to decide how many cases to run.

- Run each case until residuals drop at least three orders of magnitude, until residuals reach the level achieved in an earlier computation of the case, or until some monitored flow quantity stops changing appreciably.

- Visually examine solution (e.g. with Plot3d) to make sure there are no glaring errors.

- Plot a representative sample of data and, where possible, compare with a theoretical solution, experimental data and/or a solution from another code.

- If the previous two steps reveal problems with the solution, fix any problems with the code and repeat the above procedure until all problems are eliminated.

- Document and archive the results. (See below.)

2.2 Documentation

The first time a test case is run, it should be documented to include the items listed below. Subsequent runs will be noted in a log file, described in Section 3.0. The suggested format for the documentation is PostScript, since the documentation will contain both text and graphics. The documentation will include:

- The version(s) of the code used to run the case, and the computer hardware and operating systems used

- A brief description of the problem being solved. This should include flow conditions and descriptions of the geometry and grid

- A listing of the standard input file used to run the case (When a case consists of a series of separate computer runs, changes made to the input for subsequent runs should be noted.)

- A description of the convergence history, preferably including plots

- A representative sample of the computed results, and, where possible, comparison with experimental data and/or a solution from another code

2.3 Archive

The following files will be included in the validation archive. Unless noted otherwise, all should be plain ASCII files.

- A README file that: (1) briefly describes the case and the procedure used to run it; (2) lists and briefly describes all the files in the archive relevant to the case; and (3) provides the name, postal address, email address and phone number of the contact person for the case

- The mesh used for the calculation (32-bit IEEE Fortran unformatted form)

- The initial restart file (32-bit IEEE Fortran unformatted form)

- The standard input and output from each run

- The solution files from each run, including convergence history information. The files should be 32-bit IEEE Fortran unformatted and should be in the both of the following forms:
  - Common File 3 (CF3) format
  - Plot3d Format

- The documentation

- A log file of repeated runs. Users/developers who re-compute a flow case should add the following information to the log file: name and email address, date the calculation was made, code version used, computer software and hardware used, and comments about differences from the documented results and any relevant findings.

3.0 Testing Software Features

Much of the code development effort involves adding or improving specific code functions, and therefore test cases must be run to evaluate these functions. The table below indicates tests cases to be used for evaluating several code features. (Other cases and features may be added, as needed.) One test case is indicated for each code feature, with the exception of turbulence, which indicates one free shear case and one wall bounded case. Cases marked with an asterisk (*) have been validated for the NPARC code, and detailed information about these cases is available in the NPARC validation archive, *http:/info.arnold.af.mil.nparc/archive*. The documentation and archival procedures described in section 2.0 should also be used here.

TABLE 1. Test cases for evaluating code features.

Test Case	2D	Axi	3D	Var Width	Unsteady	Turb	Chemistry	Low Subsonic (M<0.1)	Subsonic (0.1<M<1.0)	Transonic	Super-sonic	Hyper-sonic	Multiple Blocks	Moving Grids	Artif. Viscos.
Laminar Flat Plate*	x			x											
Transonic Airfoil										x					x
Oscillating Airfoil					x										
S-Duct*			x												
Subsonic Diffuser*						x			x						
Supersonic Nozzle*		x				x					x		x		
Low Speed Flow (M<0.1)								x							
Simple Combustion							x								
Store Separation														x	
Re-entry Vehicle												x			

Appendix

NPARC VALIDATION STANDARDS

The NPARC Alliance

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1.0   INTRODUCTION

The NPARC validation effort is intended to establish the basis upon which confidence in results produced by the NPARC code is founded, and the practical limits on the accuracy of its predictions. Such confidence can only be achieved through a continuous process of careful application of the code to a wide range of "unit" and "configuration-oriented" problems and complete documentation of results. Here, "unit" refers to problems focusing on a single phenomenon and simple geometries, whereas "configuration-oriented" refers to problems which focus on geometries and flows more representative of realistic aerospace configurations. A wide variety of problems representing a mix of flows have been identified as candidates for validation cases. Cases are being run to determine the strengths and weaknesses of the NPARC code for a variety of geometric configurations, and over a range of flow parameters. Computed results are being compared with benchmark-quality experimental data, well-accepted computational results, and/or analytic solutions.

For these validation cases to be of maximum benefit to the user community, the results must be made readily available. The information should be also be detailed enough to permit the calculations to be repeated with relative ease by independent code users. A formal electronic archive system has been established to meet these criteria. This archive is the central repository for the validation cases computed by and for the NPARC Alliance. It is intended for use by NPARC users and developers, and allows easy access to the results of latest validation studies. The archive includes all the input files used to run the cases, the output files, the experimental data used for comparison with computed results, and written documentation providing an overview of each case and a discussion of the results. The archive is accessible over the Internet via anonymous ftp at *info.arnold.af.mil/pub/nparc*, and from the existing NPARC WWW home page located at *http://info.arnold.af.mil/nparc/index.html*.

The validation effort is expected to be an on-going activity and, through the NPARC User's Association, users are encouraged to propose candidate validation problems and submit documentation and results from independent validation efforts. This document is intended to assist users submitting the results from validation efforts by: (1) defining the three types of cases recognized in the NPARC validation effort; (2) describing the documentation required for each of them; and (3) listing the specific files to be included in the validation archive. Users are also encouraged to examine the existing documentation and files in the archive, and use them as examples when submitting their own results for inclusion in the archive. Questions and/or comments should be directed to the NPARC Validation Team at *nparc-validation@info.arnold.af.mil*.

2.0   MODEL VALIDATION STUDY

2.1   Definition

The term "validation" has been used in a variety of ways in the literature. In the NPARC effort, we are guided by the following definition, adapted from one given by Mehta (Mehta, U. B., "Computational Requirements for Hypersonic Flight Performance Estimates," Journal of Spacecraft and Rockets, Vol. 27, No. 2, 1990, pp. 103-112).

A code is said to be validated if the following conditions are met: (1) a comparison of computed results with detailed surface and flow field experimental data and/or other well-accepted solutions shows that the code is able to accurately model the critical physics of the flow; (2) the accuracy and limitations of the experimental data are known and understood; and (3) the accuracy and limitations of the code's numerical algorithms, grid density effects, convergence effects, and physical basis are known and understood. The range of applicability of the validated code depends on the range of flow parameters and/or geometric configurations for which the code has been validated.

Of course, in practice the accuracy and limitations of the experimental data and the computational results cannot be fully "known and understood." In addition, the degree to which the code must "accurately model the critical physics of the flow" will depend on how the results are to be used. These factors inevitably introduce some blurring of the line between the states of validation and non-validation. Nevertheless, this definition does serve to provide the necessary philosophy that guides the validation effort. NPARC validation studies which attempt to meet this strict standard are termed *model* validation studies.

Model studies are run to determine the strengths and weaknesses of the NPARC code for a variety of geometric configurations, and over a range of flow parameters. The accuracy and limitations of the code are investigated by examining the sensitivity of the results to various input options such as mesh density, turbulence model, and artificial viscosity model.

2.2 Documentation

Each model validation study is documented, in a (mostly) consistent format, as part of the validation archive. A consistent format for the documentation of validation studies is necessary to ensure an adequately thorough representation of a given study and to permit a comparison of conclusions drawn from a variety of studies. The documentation highlights the primary focus and pertinent findings, and, with the files in the validation archive, includes sufficient detail to allow independent repetition of each case.

The documentation for a model validation study should include the following elements:

* Software/Hardware Description

The version(s) of NPARC used in the study should be stated, as well as the computer hardware and operating system(s). Any other software/hardware used, such as a mesh generation package, should also be described. For parallel operation, the PVM version that was used should also be stated.

* Problem Description

The problem being studied should be described, including details about the geometry and flow conditions. The cases should be summarized in tabular or similarly compact form, showing the values of the relevant parameters that were used in the various sensitivity investigations. If the same or similar NPARC results have been presented elsewhere, those publications should be cited. The experimental data and/or computational results used for comparison with the NPARC results should also be described and cited.

* Baseline Case

One of the cases run during the study should be chosen as a baseline case. This case does not necessarily have to be the one giving the absolute best results, but should illustrate a reasonable way to run the NPARC code for the problem being studied. This baseline case should be described in detail, much like an example validation case (see below), with discussions of the reference conditions, computational mesh, initial conditions, boundary conditions, solution algorithm and time step, artificial viscosity, turbulence model, convergence history, and computed flow field results. The flow field results should be compared with experimental data and/or other well-accepted computational or analytical results. Unlike an example validation case, the documentation for a model validation case need not include a discussion of the Fortran include file, or a listing of the NPARC standard input file.

- Sensitivity Investigations

As noted above, the accuracy and limitations of the code are investigated by examining the sensitivity of the results to various input options. Exactly which input parameters should be varied may differ from study to study. As a minimum, though, the effects of the following parameters should be investigated:

- The number of mesh points. Ideally, for turbulent flow, the spacing between a solid wall and the first interior mesh point should remain constant.

- For turbulent flow, the spacing between a solid wall and the first interior mesh point (i.e., the initial y^+ value). The number of mesh points should remain constant.

- For turbulent flow, the turbulence model.

Other sensitivity investigations that may be appropriate include the effects of boundary conditions, initial conditions, artificial viscosity model and level, and time step option.

These sensitivity investigations should be described in detail. Differences in the input options for these cases, from those used in the baseline case, should be noted. The convergence histories should be discussed, and where appropriate, compared to the results from the baseline case. The sensitivity of the computed flow field to the choice of input options should be examined by comparing with the results from the baseline case, and with experimental data and/or other well-accepted computational or analytical results.

- Summary

A summary section should be included, describing the lessons learned in the validation study.

- References

A list of references cited in the text should be included.

2.3 Archive

For a model validation study, the following files will be included in the validation archive. Unless noted otherwise, all should be plain ASCII files.

- A README file that: (1) briefly describes the problem being studied   and the procedure used to run it; (2) summarizes, in tabular or   similarly compact form, the various sensitivity investigations that were done, showing the values of the relevant parameters that were   used; (3) lists and briefly describes all the files in the archive   relevant to the study; and (4) provides the name, postal address, email address, and phone number of the contact person for the study.

- The source for the program used to create the mesh, if a user-written custom mesh generator was used.

- The source for the program used to create the initial restart file.

- The initial restart file for each case, in 32-bit IEEE Fortran unformatted form.

- The NPARC standard input (unit 5) and output (unit 6) files for each run.

- The mean flow (unit 21) and turbulence model (unit 22) convergence history files for each run. These may be in ASCII or 32-bit IEEE   Fortran unformatted form, depending on the input parameters L2PLOT   and IFXPLT.

- The plot3d xyz and q files for the final run of each case, in 32-bit IEEE Fortran unformatted form.

- Any other relevant input/output files, such as the input data file for boundary conditions 30-32 (unit 3), or the output mass flow convergence file for boundary conditions 90-96 (unit 11).

- A file or files containing any experimental data and/or other well-accepted computational or analytical results, in tabular form, that were used for comparison with the NPARC results.

- The documentation, in PostScript form.

3.0 EXAMPLE VALIDATION CASE

3.1 Definition

Example validation cases are established and documented in coordination with the NPARC Support team. There are two primary goals which the example validation cases are designed to meet. The first is to provide users with quick, but limited validation of the NPARC software over a wide range of flows. These validation cases are indicative of the capabilities of the flow simulation program, but do not meet the definition of a model validation case in that they do not examine the sensitivity of the results to various input options. The second goal of the example cases is to provide the new user with clear examples of how to properly set up and execute the NPARC code for a variety of geometries and flow conditions.

3.2 Documentation

Like the model validation studies, each example validation case is documented, in a (mostly) consistent format, as part of the validation archive. Since one of the goals is to illustrate how to set up and execute NPARC, the documentation typically includes a little more detail about the mechanics of running the case, including actual input listings, than the documentation for a model validation study. The documentation for example cases is automatically provided with the NPARC code as part of the NPARC User's Guide and/or as a separate document. It is also available as part of the validation archive.

The documentation for an example validation case should include the following elements:

- Software/Hardware Description

The version(s) of NPARC used to run the case should be stated, as well as the computer hardware and operating system(s). Any other software/hardware used, such as a mesh generation package, should also be described. For parallel operation, the PVM version that was used should also be stated.

- Problem Description

The problem being run should be described, including details about the geometry and flow conditions. If the same or similar NPARC results have been presented elsewhere, those publications should be cited. If the NPARC results are being compared with experimental data or other computational results, these should also be described and cited.

- Reference Conditions

The reference conditions used in the NPARC input should be stated, and related to the geometry and flow conditions for the problem being computed.

- Computational Mesh

The computational mesh, and the procedure used to construct it, should be described. Where appropriate, such as for cases with a relatively simple customized mesh, this may include listings of the mesh generation code and input. For turbulent flow cases, the y^+ value at the first grid point from the wall, and the method used to compute it, should be discussed.

- Initial Conditions

The initial conditions, and the procedure used to construct them, should be described. Where appropriate, this may also include code and input listings.

- Boundary Conditions

The boundary conditions used for all boundary segments should be described. This should include, for each segment, the j, k, and l grid point indices defining the segment, the NPARC boundary condition code number, and the values of the auxiliary variables.

- Solution Algorithm and Time Step

The solution algorithm and method for defining Δt should be stated, especially for non-default values of ISOLVE and IVARDT. When a case consists of a series of separate computer runs, the values controlling the time step and the number of steps should be given for each run. The computer resources used, in terms of run-time memory and CPU time, should also be stated.

- Artificial Viscosity

The smoothing parameters should be discussed, especially if any non-default values are used.

- Turbulence Model

For turbulent flows, the turbulence model used should be stated. The associated input parameters controlling the model, such as IFMAX and the "EDGE" values for the Baldwin-Lomax model, should also be discussed.

- Include File

For NPARC Versions 2.2 and earlier, the parameters used in the *NPARC.INC* file should be listed. For Versions 3.0 and later, this is only necessary if changes were made to the nparc.inc file distributed with the code.

- NPARC Input File

A listing of the NPARC standard input file used for the example case (i.e., the information read from Fortran unit 5) should be included in the documentation. Since one of the goals of an example case is to show a new user how to set up and execute the NPARC code, a short description of each input item should be included, relating it to the physical problem and/or the operation of the NPARC code. When a case consists of a series of separate computer runs, changes made to the input for subsequent runs should be noted.

- Convergence History

The convergence history should be described, including the residuals for the mean flow and turbulence model equations, as well as any flow-related parameters used to determine convergence. This should include plots of the convergence parameters as a function of time step.

- Computed Flow Field Results

A representative sample of the computed results should be shown, and discussed briefly. Extensive discussion of the results, such as would be included in a report describing the solution of a flow problem, is not necessary. Discussion of specific elements of the results that are related to the operation of the NPARC code is appropriate, however.

- References

A list of references cited in the text should be included.

3.3 Archive

For an example validation case, the following files will be included in the validation archive. Unless noted otherwise, all should be plain ASCII files.

- A README file that: (1) briefly describes the case and the procedure used to run it; (2) lists and briefly describes all the files in the archive relevant to the case; and (3) provides the name, postal address, email address, and phone number of the contact person for the case.

- The source for the program used to create the mesh, if a user-written custom mesh generator was used.

- The source for the program used to create the initial restart file.

- The initial restart file, in 32-bit IEEE Fortran unformatted form.

- The NPARC standard input (unit 5) and output (unit 6) files for each run.

- The mean flow (unit 21) and turbulence model (unit 22) convergence history files for each run. These may be in ASCII or 32-bit IEEE Fortran unformatted form, depending on the input parameters L2PLOT and IFXPLT.

- The plot3d xyz and q files for the final run, in 32-bit IEEE Fortran unformatted form.

- Any other relevant input/output files, such as the input data file for boundary conditions 30-32 (unit 3), or the output mass flow convergence file for boundary conditions 90-96 (unit 11).

- A file or files containing any experimental data and/or other well-accepted computational or analytical results, in tabular form, that were used for comparison with the NPARC results.

- The documentation, in PostScript form.

4.0 CHECK CASE

4.1 Definition

Check cases will be established to judge the functionality of a newly installed and/or modified code. These will be developed, maintained, and documented in conjunction with the Development Team. The primary intent of the check cases is to provide the Development team with a tool to ensure the integrity of all mechanical aspects of code operation. At least one of these cases will be an installation check case that may be used by new recipients of the NPARC code to verify that the code has been properly installed on their computer system.

4.2 Documentation

Each check case is also documented as part of the validation archive. Since these cases are intended primarily for use by the Development Team, they do not require as much detailed documentation as the model and example cases. The documentation for check cases will be provided with the NPARC code as part of the NPARC Developer's Guide and/or as a separate document. It will also be available as part of the validation archive.

The documentation for a check case should include the following elements:

- Software/Hardware Description

The version(s) of NPARC used to run the case should be stated, as well as the computer hardware and operating system(s). Any other software/hardware used, such as a mesh generation package, should also be described. For parallel operation, the PVM version that was used should also be stated.

- Problem Description

The problem being run should be described, although not necessarily in as much detail as the model and example cases. If the same or similar NPARC results have been presented elsewhere, references to those publications should be included.

- NPARC Input File

A listing of the NPARC standard input file used for the check case (i.e., the information read from Fortran unit 5) should be included in the documentation. When a case consists of a series of separate computer runs, changes made to the input for subsequent runs should be noted.

- Convergence History

The convergence history should be described, including the residuals for the mean flow and turbulence model equations, as well as any flow-related parameters used to determine convergence. Ideally, this will include plots of the convergence parameters as a function of time step.

- Computed Flow Field Results

A representative sample of the computed results should be shown, and discussed briefly.

4.3 Archive

For a check case, the following files will be included in the validation archive. Unless noted otherwise, all should be plain ASCII files.

- A README file that: (1) briefly describes the case and the procedure used to run it; (2) lists and briefly describes all the files in the archive relevant to the case; and (3) provides the name, postal address, email address, and phone number of the contact person for the case.

- The source for the program used to create the mesh, if a user-written custom mesh generator was used.

- The source for the program used to create the initial restart file.

- The initial restart file, in 32-bit IEEE Fortran unformatted form.

- The NPARC standard input (unit 5) and output (unit 6) files for each run.

- The mean flow (unit 21) and turbulence model (unit 22) convergence history files for each run. These may be in ASCII or 32-bit IEEE Fortran unformatted form, depending on the input parameters L2PLOT and IFXPLT.

- The plot3d xyz and q files for the final run, in 32-bit IEEE Fortran unformatted form.

- Any other relevant input/output files, such as the input data file for boundary conditions 30-32 (unit 3), or the output mass flow convergence file for boundary conditions 90-96 (unit 11).

- The documentation.