Experimental and Computational Data Analysis in CHARLES and DARWIN

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Abstract

NASA Ames Research Center has developed several advanced distributed information systems to assist the distribution, analysis and management of data from experimental and numerical tests on aircraft wings and other aeronautical components. These systems provide immediate access to numerical aeronautics simulations and redefine the analysis operations for classic wind tunnel tests. The information systems built to make this possible are called CHARLES, enabling distributed access to computational fluid dynamic results, and DARWIN, which enables wind tunnel test results to be produced and made available to industry customers in near real time from active tests and from archival storage. This paper will provide details on data analysis with the DARWIN and CHARLES systems.

1 Introduction

Typically, a aeronautics wing design activity requires the generation of extensive computational fluid dynamic (CFD) numerical simulations to establish the design points of an aircraft well prior to any physical hardware being built. After the basic design is complete, experimental wind tunnel tests are needed to evaluate the expected performance against the computed performance.

Performing a wind tunnel test requires bringing a team of technicians and engineers with the experimental wing to a single test location. The engineers must travel to the test site to have access to the data. Gathering the results of the test and interpreting the data is generally time consuming and can take up to six months. Comparing the CFD data with the experimental data is often left to single plots of critical variables. It is so difficult to generally compare the two types of data that it is often done months later, if ever. When all the data reaches aerospace industry customers the results often provide valuable insights and reveal areas that could have been explored if those results had been immediately available during the test.

NASA Ames Research Center is currently using DARWIN to remotely access and quickly distribute to customers the information from current and archival experimental wind tunnel tests. DARWIN provides user authentication and privacy, data security, advanced video and interactive conferencing tools, remote control of cameras, remote interactive database access, and custom tools for data visualization and analysis. CHARLES manages CFD solutions and allows archival analyses and comparisons between CFD datasets as well as with the experimental data from DARWIN. This allows researchers to perform remote analyses, to communicate timely results to aerospace industry customers, and interact remotely with other NASA /Industry engineers without incurring travel and other costs.

The client framework for DARWIN and CHARLES remote access elements is a web browser that operates over the internal NASA AEROnet and NREN (NASA Research and Education Network) extranets. Specialized data analysis and visualization tools are integrated with the browser to enable users to make detailed interpretations of the data.

The hub of the distributed aeronautics information infrastructure is a central system with links to appropriate customers or sources of information. Using distributed web links instead of a central data repository allows designers and organizations to control access and integrity of their data and distribute storage requirements of information. This allows efficient access for authorized data retrieval in usable formats. In this manner, the broad spectrum of aeronautical customers from Boeing, Lockheed-Martin, Pratt & Whitney, General Electric, etc. will be provided with a national information web for multiple sets of data from the overall design process.

The goal of this infrastructure is to provide the foundation to achieve aeronautics design cycle iterations within a single entry to a test facility. This capability requires complete and efficient access to all relevant design cycle information from wing model design and geometry, CFD solutions and grids, wind tunnel and instrumentation data, and ultimately access to rapid prototyping facilities to construct new models in an appropriately short period preceding facility test entry. The infrastructure is designed to provide the aeronautical researcher/designer with access to enough relevant information and knowledge in real-time to allow for responsive and informed design decisions.

2 DARWIN

The DARWIN distributed aeronautics information system consists of the DARWIN Workspace, the client systems at the remote user sites, the servers in the aeronautics test facilities (wind tunnels, flight control rooms, etc.) and the central DARWIN server. These systems are all connected utilizing DARWINnet at Ames and AEROnet for national connectivity [1].

The remote access system is based on a three-tier client/server/server architecture and is distinct from the traditional client server. The first server is the DARWIN MetaServer [2], running a secure HTTP (hypertext transport protocol) or web server, the supporting central executive server software, and the DARWIN meta-database [3]. The third tier server is the data server which is hosted in the aeronautics test area of choice. The remote client system hosts the DARWIN Workspace environment that is composed of a secure web browser, an executive, and additional visualization and collaboration software. Initialization and startup of all remote processes on the data server, DARWIN MetaServer, and client is done via the secure web links. Many of the small remote applications are written in Java or Javascript as remote objects that are either executed or started by the client's browser. The larger applications, such as the collaboration whiteboards, remote video tools, and higher end data visualization tools are authorized and initiated by the executive software on the client or through the DARWIN MetaServer.

1.1 CHARLES / DARWIN client

The CHARLES and/or DARWIN client is a (UNIX, PC, or Mac) workstation with a digital video and audio system to permit remote collaboration. The video conferencing software allows researchers to communicate timely results to aerospace industry customers, as well as interact remotely with other NASA engineers on-site. A system in the wind tunnels is connected to a video-switcher to allow multiple cameras to show different views of the wind tunnel, the test models, and the various control systems. This video data is then shared via digital video tools with the remote clients. Client systems will host the CHARLES and DARWIN Workspaces and additional data visualization tools.

1.2 DARWIN Workspace

The DARWIN Workspace [4] software controls user authentication and privacy, data security, advanced video and interactive conferencing tools, remote control of cameras, interactive database access, and custom tools for data visualization and analysis. The framework for the DARWIN Workspace is composed of a web browser, specifically Netscape Navigator™ v3.01+ that can display HTML containing text, Javascript code, and Java applets; the DARWIN executive software; and supporting data analysis applications. The browser and the applications are all resident on the client workstation. The web pages, which are the dynamic results of the DARWIN executive software, are retrieved from the DARWIN MetaServer via secure HTTP over the DARWINnet and AEROnet communications network.

The DARWIN executive software provides the communication link between the web browser and the specialized data analysis tools. The executive software is written in PERL, Java, and JavaScript. These cross-platform interpretive languages are easily understood and provide a simple way to distribute a cross-platform graphical interface tool built upon an HTTP browser. The executive's role is to coordinate the browser-related applications and the additional visualization and collaboration tools. The executive sends signals to the browser telling what information pages it should be displaying and coordinates the signals sent to the server-side and the client collaboration tools.

To access data from a particular wind tunnel test, a DARWIN user logs in to the system by selecting the test hyperlink from the DARWIN server and then entering a user name and password. The Internet protocol (IP) address of the requesting computer is also checked against a list of allowed machines before access is granted. Once logged in to the DARWIN system, the user is presented with links to the tests that he/she is permitted to review. The front page for a wind tunnel test typically contains a summary of the test's purpose, statement of progress, access to the test engineer's log, and various views on the data collected, such as a listing of the latest runs from the wind. All of this is dynamically generated on the DARWIN MetaServer from the information available in the meta-database.

The DARWIN Workspace can directly display or plot most of the raw data files in the DARWIN meta-database and file system. The browser's point-and-click interface allows the user to interrogate specific runs by querying appropriate meta-data and then automatically retrieving and presenting the information. Dynamic plots of the data are generated using a graph package written in Java. The user may also customize the display of data by using a form-based interface to specify preferences for what plots should be generated and what columns should appear in the summary tables. The linkage between the information presented and the related data sets is the enabling factor in being able to dynamically access the data and generate knowledge from the test.

For in-depth analysis, more complex manipulation of the files is required than the browser-based applets can provide for evaluating and interpreting the data. The DARWIN Workspace enables an intelligent data-visualization element that incorporates and presents the information from the database. The system is capable of automatically extracting meta-data information and properly passing the information directly to remote data visualization tools. This is coupled with the use of collaboration software to share and edit documents. This collaboration is invaluable in aiding remote discussion and sharing of data during a wind tunnel test.

2 CHARLES

CHARLES, a computational, historical analytical results system, is in principal very similar to DARWIN. The same issues drive this system - large data sets generated, and the difficulty in providing wide spread access to and ease of comparison and analysis of the data. CHARLES is a distributed interface to the meta-database of computational and numerical results.

CHARLES has a similar MetaServer and Data server architecture as DARWIN. However, instead of wind tunnel data being loaded at each test point, CFD solution files are loaded from the supercomputer. Only selected CFD solutions are loaded into CHARLES. These solutions and their associated meta-data are posted into CHARLES.

The CHARLES meta-data focuses on the values that are of most interest to the aerodynamicist and wind tunnel experimentalist. The derived values of lift and drag at two-dimensional cross sections are obtained from post-processing the CFD solutions. These derived values and any others are also stored in the CHARLES meta-data.

For the wind tunnel experimentalists, CHARLES provides a system for reviewing existing numerical solutions and comparing them to tunnel data as it is collected. If no comparable numerical results exist, a mechanism is being developed to request the NASA Ames CFD design system [5] to produce an appropriate solution. The NASA Ames CFD design system has been developed with a user interface that leads the designer through the setup of a flow solver and provides advice on configuring it correctly for a valid solution or sets of solutions.

Typically CFD simulations are done well in advance of commencing testing in the wind tunnel. However, situations may arise during a wind tunnel where none of the numerical solutions done ahead of time adequately models the current wind tunnel conditions. In this case, the test engineer may use NASA's CFD Design System to produce a new simulation and identify flow features of the resulting solution file. Once the CFD Design system solver has produced a converged solution, the CHARLES data server posts the solution file and meta-data to the database. Then the test engineer can use the CHARLES feature extractor component to check for expected flow features such as shocks or vortices. Fluid dynamicists could also use this system to launch codes and track the solutions, as well as have access to experimental data for analysis and review.

3 Data Visualization and Analysis

There are currently eight analysis tools that were written to be components for the DARWIN and CHARLES systems. These include client and server components and two helper standalone applications.

The first set of analysis tools is the server-side components. One of these is a neural net modeler [6] being developed to allow predictions based on variations of wing flap and slat positions and deflection angles. A neural network is being trained to accurately predict the effects of these parameters on the aerodynamic coefficients (lift, drag, side-force, pitching moment, yawing moment, and rolling moment) using a smaller subset of the test runs than would normally be required to generate an adequate database. It is believed that a significant cost savings in test time and associated costs could be realized. The reduced testing time would directly impact the cost of testing.

The second server component is a statistical estimator used to fit non-linear models to the input variables against various output variables. This is possible because across the different tests, and within tests, the graph of the coefficient of lift (CL) versus the angle of attack (alpha) has a characteristic shape. In the range, alpha from –10 degrees to near 25 degrees or so (near the stall point), the graph is almost linear with a positive gradient. At the stall point, the CL then drops off. The way it drops off varies quite dramatically for similar inputs. It is common for test runs to differ imperceptibly in the near-linear part, but then dramatically differ after the stall point.

All the statistically fitted curves will have error bars as an indication of the uncertainty in the prediction. These predictions and error-bars are used as follows: to predict the stall-points of runs (with error-bars) given initial or no data for the run to produce a "test-map" of error-bars, this will suggest where further test runs may be needed.

The last server component is the feature extraction component [4]. For a given CFD solution a feature recognition component of CHARLES can automatically identify a variety of flow features, such as shocks and vortices, which can then be compared with wind tunnel results.

The next set of analysis tools consists of the Java graphical presentation elements that enable data to be dynamically presented in the client browser. There are three Java components, a two-dimensional plotting and graphing tool, a three-dimensional version of the plotting tool, and a multi-image animator to sequence through images. The plotting components are very useful for the presentation of the tabular data in a graphical manner.

Finally, there are two UNIX applications written to work in conjunction with CHARLES and DARWIN systems. The first is called exVis, which is short for the experimental visualization system [7]. This system can natively handle the file formats of the wind tunnel and CFD solutions to produce high-end visualizations of the airflow over a wing.

The other application is called FASTlook [4]. This is a visualization tool to graphically show the placement of the fluid flow features extracted from the data by the feature extraction component. This also displays the features overlaid on the physical model's computational solver grid.

4 Conclusions

The DARWIN and CHARLES distributed remote analysis and management systems give test engineers the capability to evaluate the test data as the data is collected. In addition, DARWIN provide access to archival data for cross test comparisons, and CHARLES provides access to archival CFD solutions and a link to the CFD design system for starting numerical simulations of wind tunnel runs while the wind tunnel test is still in progress. Any insights gained by comparing tunnel data with other tests or computational models can thus be applied to improving and fine-tuning further collection of data during the test. The DARWIN and CHARLES systems are designed to provide the aerospace customer with the necessary information access to greatly improve the design cycle process by gleaning more knowledge from available data and thus providing the capability to perform true design cycle iterations in single wind tunnel test entry.

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