

LiveView3D: Real Time Data Visualization for the Aerospace Testing Environment

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This paper addresses LiveView3D, a software package and associated data visualization system for use in the aerospace testing environment. The LiveView3D system allows researchers to graphically view data from numerous wind tunnel instruments in real time in an interactive virtual environment. The graphical nature of the LiveView3D display provides researchers with an intuitive view of the measurement data, making it easier to interpret the aerodynamic phenomenon under investigation. LiveView3D has been developed at the NASA Langley Research Center and has been applied in the Langley Unitary Plan Wind Tunnel (UPWT). This paper discusses the capabilities of the LiveView3D system, provides example results from its application in the UPWT, and outlines features planned for future implementation.

I. Introduction

Thorough aerodynamic analysis of any proposed vehicle configuration requires a careful assessment and understanding of the off-body flow physics, on-body surface flow properties, and structural aeroelastic characteristics. Although computational fluid dynamics (CFD) and finite-element modeling (FEM) codes can now provide predictions of these aerodynamic characteristics, a significant portion of vehicle aerodynamic assessment is still accomplished by wind tunnel testing. A number of different optical diagnostic techniques currently exist for measuring the flow and structural properties of wind tunnel models under test¹. Extracting knowledge from these extensive data sets, often gigabytes per test condition, requires efficient and revealing data visualization methods. Most data produced by currently available optical instrumentation techniques are processed off-line, and full analysis may not occur until weeks or months after the test. However, the cost of wind tunnel operations and the complexity of interrelated aerodynamic phenomena being investigated are pushing the requirement of real-time data visualization and analysis. Real-time data visualization can dramatically improve the knowledge and understanding of the physical processes and aerodynamic behavior occurring during a test. This knowledge and understanding can then be used to alter the test matrix to focus on conditions of interest, thus maximizing the test value while contributing to minimizing the test cost.

The LiveView3D software and data visualization system has been developed to provide the ability to view data from wind tunnel instrumentation systems in an interactive virtual environment in real time. LiveView3D is an extension of the Virtual Diagnostics Interface (ViDI) technology¹ previously developed for pre-test planning and post-test data visualization. The primary distinction between ViDI and LiveView3D is that ViDI is a “usage methodology” of commercially available software, and LiveView3D is a custom-written software package that utilizes ViDI technology. ViDI is predominantly used for pre-

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³test planning and post-test data visualization, while LiveView3D is used for real-time data visualization during wind tunnel operations.

LiveView3D has been used for real-time data visualization for several developmental tests in the NASA Langley Research Center Unitary Plan Wind Tunnel (UPWT). This paper will further describe the LiveView3D software and data visualization system, and will illustrate the system capabilities using imagery obtained during the developmental tests in UPWT. Although system development continues, LiveView3D has successfully been used during tests for external customers to visualize off-body flow structures and surface pressure distributions.

II. LiveView3D Software and Data Visualization System

The LiveView3D data visualization system is based on a workstation-class PC-compatible computer using the Windows* XP operating system. The computer is equipped with a commercially available video frame grabber capable of capturing video from industry standard RS-170 grayscale video cameras. Frame grabbers suitable for use with other video transmission protocols could be used with only minor modification to the LiveView3D software. The computer is also outfitted with a professional-grade graphics card with dual monitor outputs. These outputs are connected to two displays (typically 19-inch flat panel monitors or larger) for use by the researcher. No other specific hardware components are required for the current LiveView3D configuration. Of all the hardware components required, a high quality, professional grade graphics card has been found to be the key to achieving smooth rendering and high quality real-time data visualization. As a benchmark, the computing hardware required to comprise a LiveView3D system is estimated to cost approximately \$5,000 in 2005 USD.

The LiveView3D software consists of two separate computer programs that work in unison; the LiveView3D Controller and the three-dimensional graphical visualization environment. The LiveView3D Controller is a custom computer program written in Microsoft Visual Basic®. The Controller provides a graphical user interface to allow the researcher to control various aspects of the data visualization, and to save and recall data streams for display. The Controller also controls aspects of video capture from the frame grabber card, data acquisition from other sources, and overall data flow. The three-dimensional graphical visualization environment is provided by Autodesk® 3ds Max®. 3ds Max® is a CAD-like software package with advanced modeling, lighting, rendering, and animation toolsets for generating very high quality interactive visualizations. The LiveView3D Controller communicates with 3ds Max® using the Microsoft ActiveX® protocol. This allows user input parameters from the Controller to be passed to custom-developed code within 3ds Max®, whereby the user-requested changes to the visualization are implemented. The custom codes are written in MaxScript, which is a programming language inherent to 3ds Max®. MaxScript provides access to virtually all features of 3ds Max® and provides support for inter-program communications using the ActiveX® protocol.

During operations, two video monitors are used for user interaction and data visualization. Typically, the LiveView3D Controller is displayed on one monitor, and the real-time data visualization within the 3ds Max® environment is displayed on the other. Figure 1 shows a typical view of the LiveView3D system in use for real-time flow visualization.

III. LiveView3D Visualization Capabilities

A. Real-Time Streaming Video

Real time streaming video can be made available from a number of powerful flow visualization techniques. Examples include laser vapor screen, schlieren, and IR thermography. These techniques allow

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researchers to determine prominent flow features such as the location of vortices, shocks or transition. However, the output of these techniques has typically been limited to images from a single instrument, with data presentation isolated from representations of the test environment or other forms of data. Additionally, the view of the data is from a single perspective. Using LiveView3D, this imagery is mapped into the three-dimensional virtual environment in real time. This allows the user to navigate through the three-dimensional environment as the data is being received. The user may view the scene from any angle and hide or unhide various hardware elements of the test configuration and facility. The magnification factor can be adjusted to encompass the entire scene or limit the field of view to a small region of interest. Also, data from previous tests or from computation can be included in the visualization, for comparison in real time. Using LiveView3D, a broad spectrum of information can be placed in front of the user in a concise and timely manner.

Test data imagery in the form of standard NTSC or RS-170 video can be captured and digitized in real time by COTS framegrabber hardware integrated into the computer running LiveView3D. To control the framegrabber the manufacturer provided ActiveX® controls that were incorporated into the LiveView3D Controller program. Hardware features such as gain settings, image contrast and brightness, and low-level pixel thresholding (where pixel levels below a preset limit are equated to zero) can be accessed through these controls and associated with elements of the graphical user interface (figure 1).

The framegrabber manufacturer also offers a comprehensive library of image processing tools designed to work with the images captured from the framegrabbers. This library is accessed through the ActiveX® protocol, and offers capabilities for enhancing the video stream in real time. One set of functions available through this library enables the application of false colors to the video stream in real time. The Controller program allows the user to choose from a variety of grayscale or color palettes to enhance the visualization.

Background subtraction is an effective way of enhancing video quality by limiting the effects of stray and ambient light. For laser light sheet visualization, this can reduce the amount of glare often present due to the laser light striking the model. The image processing requires acquiring a background image, typically an average of several consecutively acquired images. For example, with laser light sheet flow visualization this was accomplished by having the user capture images of the test configuration with the laser and any background illumination source turned on, but without the introduction of smoke in the flow. A background image is required for each position of the laser light sheet with respect to the model. If model deflection under loading is significant, this must be done under the proper flow conditions. Once the smoke is introduced into the flow the background image is subtracted from the streaming video frame-by-frame in real time.

In addition to viewing the data in real time, a video stream can be played back from a standard recorder or other such device that can provide a compatible stream of video. LiveView3D also has the capability to record each frame of video to hard disk while it is displaying the data interactively. Each frame is saved as an uncompressed bitmap. Since only the input video is saved, LiveView3D treats the playback of the saved imagery as streaming video, giving the user all of the flexibility to interact with the virtual environment as offered by the real time data visualization.

It is also possible to combine data from previous testing. IN the case of laser light sheet visualization, multiple planes of laser light sheet data were acquired at a given condition. Data was recorded at each location, and multiple planes of data were made visible in the visualization. However, test data does not necessarily have to be from the same test, or even of the same type. In the section below, the discussion turns to how a variety of forms of data from the wind tunnel Data Acquisition System (DAS) have been incorporated with LiveView3D, and how it has been made to display data in unison with the live video.

B. Graphical Representation of Scalar Parameters

The existing DAS at the UPWT is based on a UNIX operating system MODCOMP computer. Using legacy software, the LiveView3D Controller was interfaced with the DAS via an Ethernet-based TCP/IP protocol via Windows sockets. It was designed to acquire hundreds of channels of data from a

variety of sources throughout the facility and from the test configuration. The DAS will convert many channels of data into engineering units or dimensionless coefficients in real time. All of these values are available to LiveView3D.

One form of DAS data visualized in LiveView3D was from surface pressure taps. In order for discrete points of scalar values such as surface pressure tap data to be visualized in three-dimensions, an artificial contrivance must be created in the virtual environment. In this case, a solid model of a cylinder was modeled in the virtual environment to represent a single tap. A cylinder in the virtual world represented a tap in the real world. The cylinders were distributed along the surface of the virtual model just as the surface pressure taps were distributed on the actual test model. Using the LiveView3D Controller, the user was able to map channels of DAS data to the three-dimensional objects in the virtual environment, choosing to display the data in units of pressure or as coefficients of pressure, C_p . This pressure data was then used to modify the length of the cylinders, and vary the color. The resulting visualization allowed the user to see the pattern of pressure distribution from all of the pressure taps at once by seeing the size and color of the "pressure tap cylinders".

An issue that arose was how to differentiate between positive and negative values of pressure or C_p . While a positive data value was displayed by having the cylinder representing the surface pressure tap extend outward from the surface, a negative value resulted in the cylinder being extended into the surface, or volume, of the model. Using the comprehensive modeling capabilities of 3ds Max, the virtual model was assigned a partially opaque glass material. This allowed the user to see through the object while still having the ability to define the outer mold lines of the airframe. Under these visualization conditions, it was possible not only to tell the sign and the magnitude of the pressures, but also to view all of the pressure taps distributed across the model simultaneously while still putting them in context in three-dimensional space.

Another feature of the LiveView3D Controller was the ability to organize pressure taps into a number of individual groups. Using a graphical user interface that depicts all of the pressure taps in the virtual environment, the user may select single or multiple taps to be in a group. Once grouped, the user has the ability to enable or disable the visualization of any particular group. These groups also play an important part in plotting pressure values on conventional X-Y data plots, a feature of LiveView3D that will be discussed below.

In addition to surface pressure taps, data from force balances can be displayed in a three-dimensional context. It is common for six-degree-of-freedom force balances to be used in the UPWT. Data from the balance is recorded by the DAS, and converted into engineering units and dimensionless coefficients. To display the force data in three-dimensions, a set of orthogonal reference axes aligned with the measurement axis of the balance are created from small radii cylinders. The actual depiction of the force data is by larger cylinders topped with cones to appear as arrows, and projected along the reference axes. The magnitude and color of the arrows indicate the magnitude of the data.

Moment data from the balance is depicted in a similar fashion to the force data. However, the reference lines are shown as hoops around the axis that the moment acts upon. The moment data appears as an arrow following the arc of the reference hoop, again with length and color depicting the magnitude of the moment data. Both the force and moment data may be multiplied by gain factors by the LiveView3D Controller in order to enhance the visualization.

IV. Operation of LiveView3D

Initial demonstrations of the system conducted in the Langley Unitary Plan Wind Tunnel (UPWT) illustrated the flow visualization capabilities provided by the LiveView3D system (figure 2). The UPWT is a closed loop, continuous running supersonic test facility capable of speeds up to Mach 4.6². To date, the full capabilities of LiveView3D have been used for two entries in the UPWT. These tests were standard operation for the UPWT; LiveView3D was run in the background for developmental purposes. Since both tests consisted of proprietary configurations, graphical output from the tests is restricted. However, a description of the operation of LiveView3D during this testing is given below.

The first step in preparing for a test is to receive and import a three-dimensional CAD model of the test configuration, which is usually provided by the customer. Typically this is a file created by the model makers or a model used for Computational Fluid Dynamics (CFD) modeling, often in an IGES file format from a UNIX workstation CAD software program. Under most circumstances, importing such geometry files into 3D Studio Max is a straightforward process. The geometry is scaled and mated to baseline geometry of the sting and the wind tunnel facility.

If a live video feed is supplied to LiveView3D, the video data is mapped to a plane placed in the virtual environment. For laser light sheet flow visualization, this plane corresponds to the location of the laser light sheet with respect to the model (figures 3,4,5). For schlieren, the data plane is aligned along the center of the wind tunnel test section, parallel to the direction of the flow. Using reference marks in the video, the data is scaled to match the virtual model.

When surface pressure taps are included in the test, the cylinders required to visualize the taps are created. A utility program has been written to automatically align cylinders to the surface of the model, and future implementations will allow the cylinders to be formed and placed in three-dimensional space from coordinates in data files. To date, over 150 surface pressure taps have been included in a single visualization.

With the geometry prepared, the user establishes communications between LiveView3D and the DAS. A pre-compiled list of data values to be sent from the DAS to the LiveView3D Controller is recalled, and the two computers establish communications (figure 6). The LiveView3D Controller can be manually made to receive the last data point acquired by the DAS, or the program can be put into a loop whereas it queries the DAS at 2 Hz to determine if new data has been acquired.

Once LiveView3D receives data from the DAS, it parses the information to send the appropriate values to the proper places. Data concerning the wind tunnel is sent directly to the LiveView3D Controller interface, which displays the current test, run, point, Mach number, dew point and other pertinent information. Model roll, pitch and yaw data is both displayed in the LiveView3D Controller interface, and sent to the three-dimensional computer model, where the sting is adjusted to depict the model in its current attitude. Pressure tap data is routed such that it is assigned to the proper cylinder in the virtual model, and then the cylinder size and color is modified to represent the pressure (figures 7, 8). A similar process occurs for the force and moment data.

The software is typically placed in a mode where it continuously queries the DAS for new information. When a new data set is found, the data is transferred, the virtual model geometry is adjusted to the proper roll, pitch and yaw, and the pressures and forces are displayed. With schlieren, a single shot of video data is acquired as soon as LiveView3D realizes the DAS has taken a new data point. All of this data is relayed to 3D Studio Max for display in the virtual environment. The LiveView3D Controller saves all of the data it receives automatically by creating directory structures on the PC based on the test, run and point information of a particular data set. Under normal operation, all data handling is automated. This leaves the user free to interact with the virtual environment, navigating thorough the scene to gain the best vantage points for viewing the flow of data (figure 9).

In addition to the ability to view the data in the virtual environment, it is also possible to create X-Y plots of the data. Through the LiveView3D Controller, the user is given the ability to select values for the X- and Y-axis. The X-axis values may include a distance or position, or the roll, pitch or yaw of the model. The Y-axis can represent pressure, force, or moment data. As mentioned above, data from an individual group or groups of pressure taps can be displayed.

Another visualization feature of the software is display rendering. If enabled, the LiveView3D Controller will command 3D Studio Max to make a rendering of the current view, creating a bitmap image of the data visualization. This bitmap is then imported into LiveView3D automatically, where the test, run, and point information, as well as pertinent wind tunnel conditions and color bars indicating the range of pressure or force balance data are overlaid. This enhanced graphics is then saved as a bitmap along with the individual data elements that went into creating it.

Once the test is completed the data stored by the LiveView3D Controller can be recalled, and the user may visualize any portion of the test data. Since the data was saved and recalled in its original format, all of the interactive visualization capabilities present during the real time acquisition operation are available to the user in playback mode. In addition, data files saved by the DAS, which contain all of the parameters recorded during the test, can be imported into the LiveView3D Controller. Thus, even if a parameter was not initially displayed in real time, it can be incorporated into the visualization in playback mode. Multiple combinations of data sets may be viewed in this way, creating unique ways of comparing data from a wide variety of sources.

V. Future Work

There are numerous ways in which LiveView3D can be expanded to incorporate more information and to enhance usability. LiveView3D was written in a modular format, with portability and future expansion in mind. Data from various forms of image based instrumentation³, such as Pressure Sensitive Paint (PSP), Projection Moiré Interferometry (PMI), or Particle Image Velocimetry (PIV) can be incorporated into the visualization, as well as scalar values from instruments such as thermocouples. Introducing the software to new facilities will require new modules to interface with the various data acquisition systems. Interface changes required to customize the program for a particular facility are generally straightforward modifications, with the core visualization and data handling routines remaining unchanged.

One of the main goals in the future is to have real time comparisons between experimental data and CFD and FEM predictions^{4,5}. Figure 10 is a rendering that has combined PSP data and CFD data for surface pressure⁴. When this test was held, the ability to do real time comparisons did not exist. However, by further developing LiveView3D to organize and manipulate CFD data, we can project the experimental data, in real time, along with a pre-computed CFD solution of the same condition. With expanded analysis tools built into LiveView3D, direct comparisons can be made while the wind tunnel is still “on-point”.

VI. Summary

The LiveView3D system has been developed into a powerful data visualization tool designed for real time data analysis. To date, it has incorporated streaming video from laser light sheet and schlieren systems, along with pressure and force balance data from DAS systems. Tools for both qualitative and quantitative data analysis have been built into LiveView3D, providing researchers with an unprecedented capability to comprehend hundreds of channels of scalar data along with image based data in real time in an interactive virtual environment. As development continues, LiveView3D will become an ever more capable tool for converting information into knowledge.

Figures

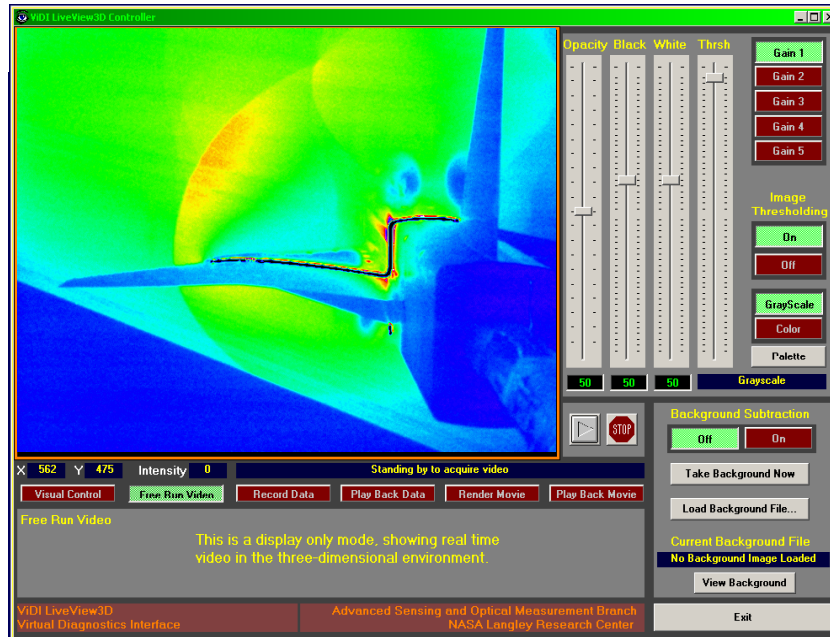


Figure 1. Original interface for LiveView3D streaming video operation. This interface prominently features the framegrabber and file handling functions of the LiveView3D system.

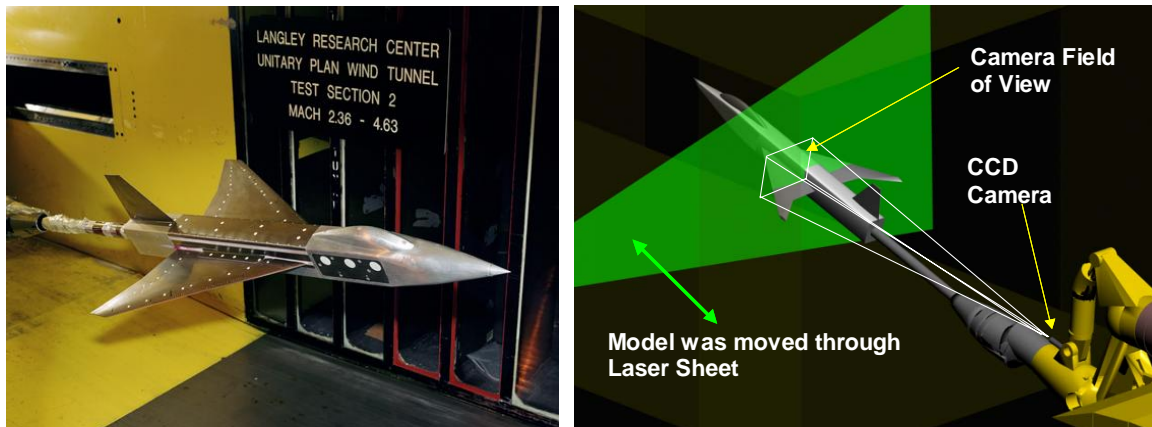


Figure 2. A Unitary Plan Wind Tunnel (UPWT) laser light sheet flow visualization experiment configuration for a LiveView3D application.

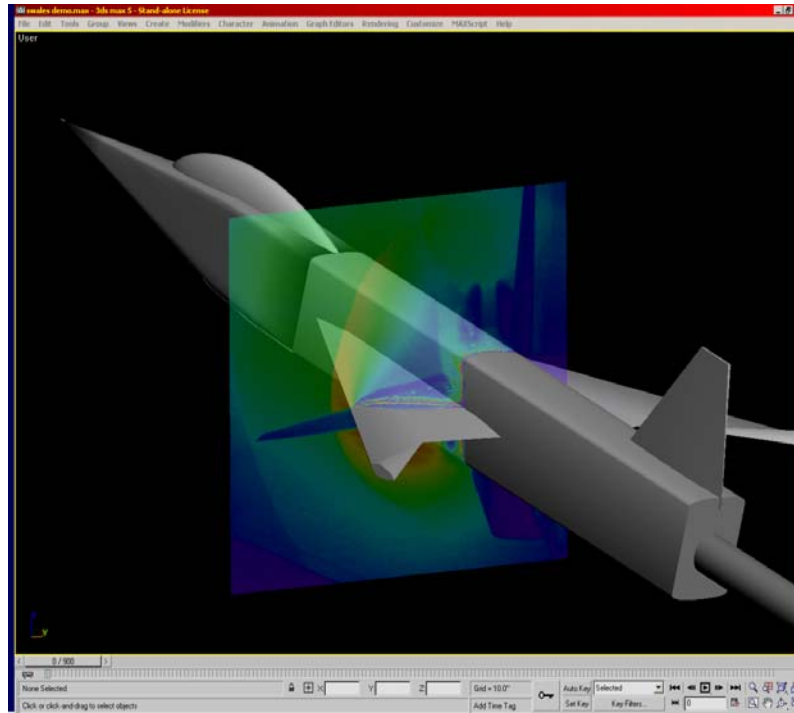


Figure 3. Interactive Virtual environment display with video data corresponding to Figure 2.

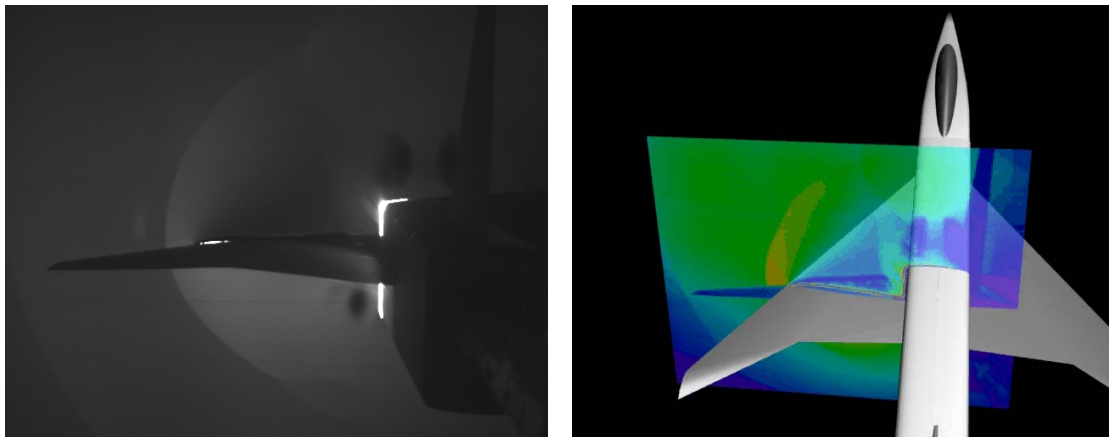


Figure 4. Comparison between original static flow visualization

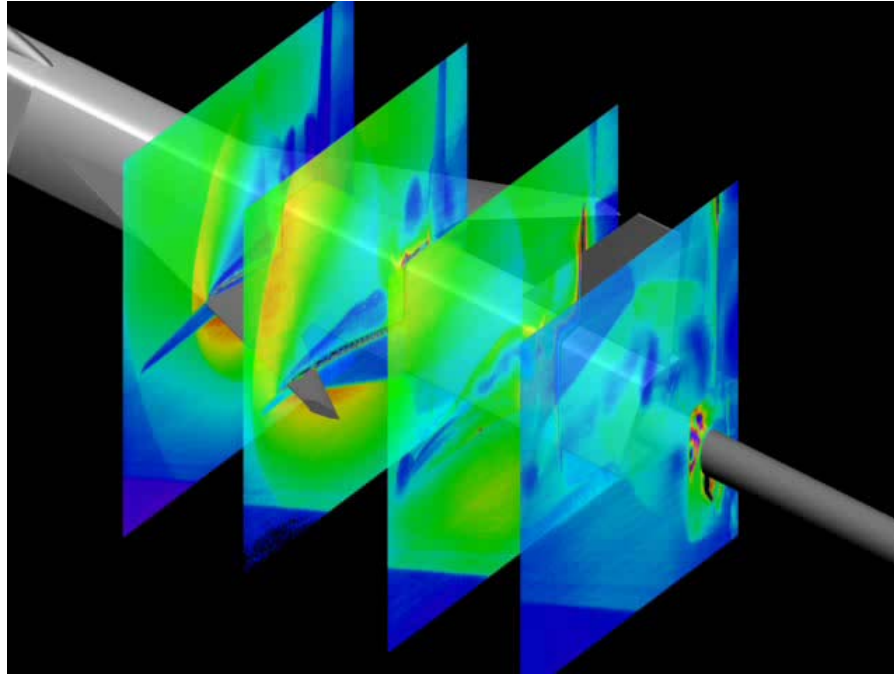


Figure 5. Multiple data planes combined following the test. Each data plane can have animated data. The combined data sets can be viewed in the interactive environment, or rendered to a movie format file.

VIDI LiveView3D Data Control Center

DAS Pressure Taps Force Balance Live Video Thermocouples CFD Render / Display 2D Plots Data Organization Exit LiveView

DAS Off Line Enable Enable Enable Enable Enable Enable Enable

Test Run Point Batch Mach Alpha, deg Roll, deg Yaw, deg Dew Pt Re # H T

DAS TCP/IP Communications

DAS System: Unitary A, UPWT88KA

Tunnel DAS IP Address: 146 165 127 111

Communications Port: 50000

Connect to DAS

Disconnect from DAS

Open Parameter List... Save Parameter List...

Add Parameter Update Parameter Remove Parameter

On None None

Index	Description	DAS Mnemonic	Units	3D Object
<input checked="" type="checkbox"/> 1	Current Test Number	TEST	None	None
<input checked="" type="checkbox"/> 2	Current Run Number	RUN	None	None
<input checked="" type="checkbox"/> 3	Current Point Number	POINT	None	None
<input checked="" type="checkbox"/> 4	Current Batch Number	BATCH	None	None
<input checked="" type="checkbox"/> 5	Month	MONTH	None	None
<input checked="" type="checkbox"/> 6	Day	DAY	None	None
<input checked="" type="checkbox"/> 7	Year	YEAR	None	None
<input checked="" type="checkbox"/> 8	Hour	HOURL	None	None
<input checked="" type="checkbox"/> 9	Minute	MINUTE	None	None
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<input checked="" type="checkbox"/> 11	Dew point	DEWPT	None	None
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<input checked="" type="checkbox"/> 16	Dynamic Pressure	Q	None	None
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<input checked="" type="checkbox"/> 18	TO	TO	None	None
<input checked="" type="checkbox"/> 19	Alpha	ALPHA	None	None
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<input checked="" type="checkbox"/> 21	Phi	MODROL	None	None
<input checked="" type="checkbox"/> 22	Pressure Tap	CPM101	None	Tap8
<input checked="" type="checkbox"/> 23	Pressure Tap	CPM102	None	Tap28

Refresh Geometry List

3D Geometry List

- Tap15
- Tap51
- Tap16
- Tap17
- Tap18
- Tap19
- Tap20
- Tap21
- Tap22
- Tap23
- Tap24
- Tap25
- Tap26
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- Tap44
- Tap45
- Tap46

Figure 6. Portion of LiveView3D DAS communications and data assignment user interface. The user may select DAS channels (center columns) and assign corresponding three-dimensional geometry objects to represent the data.

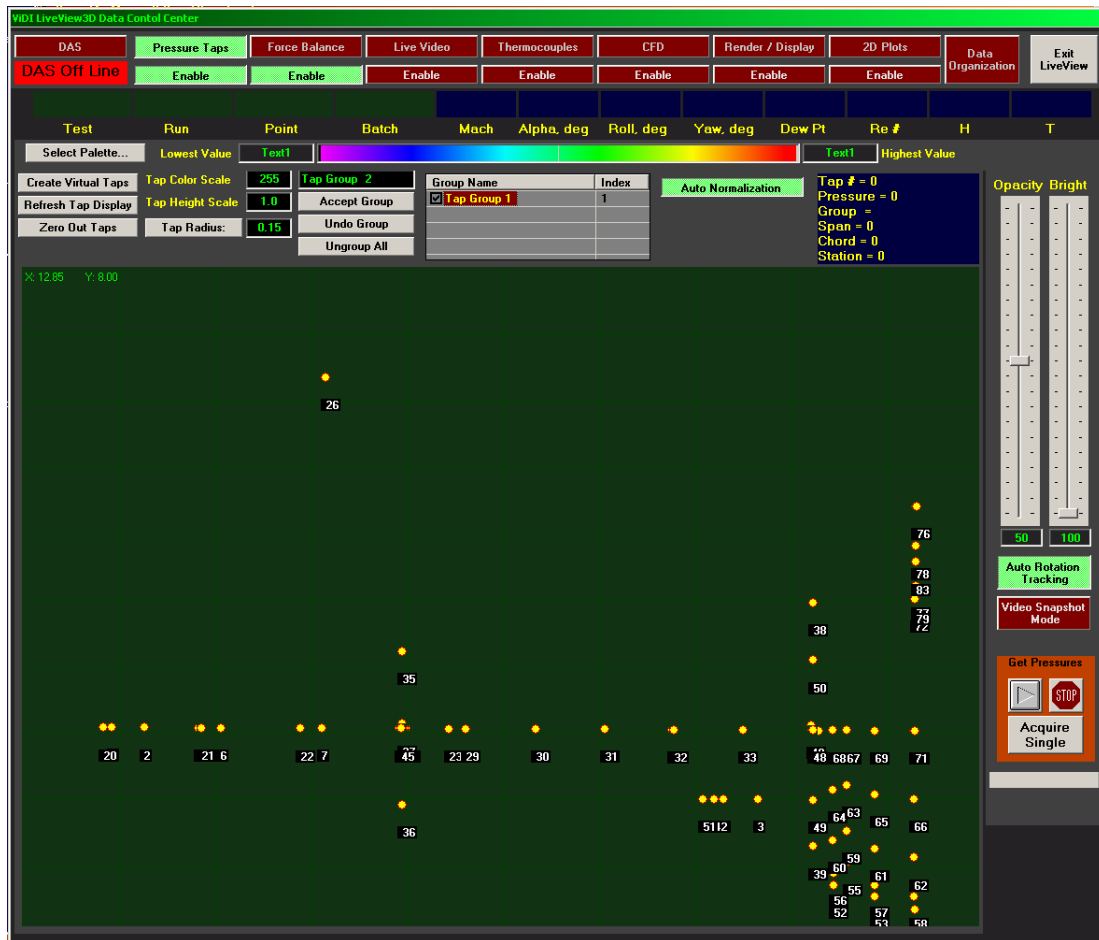


Figure 7. LiveView3D Pressure tap user interface. The yellow dots represent the pressure tap located on the surface of the model. The user can group together taps and enable or disable the display of individual taps or groups of taps.

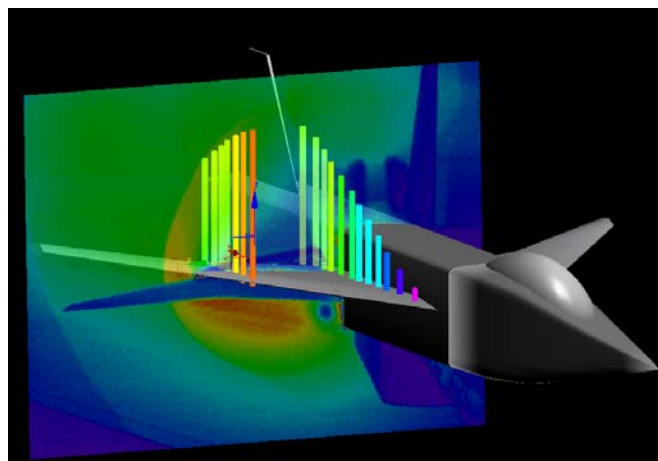
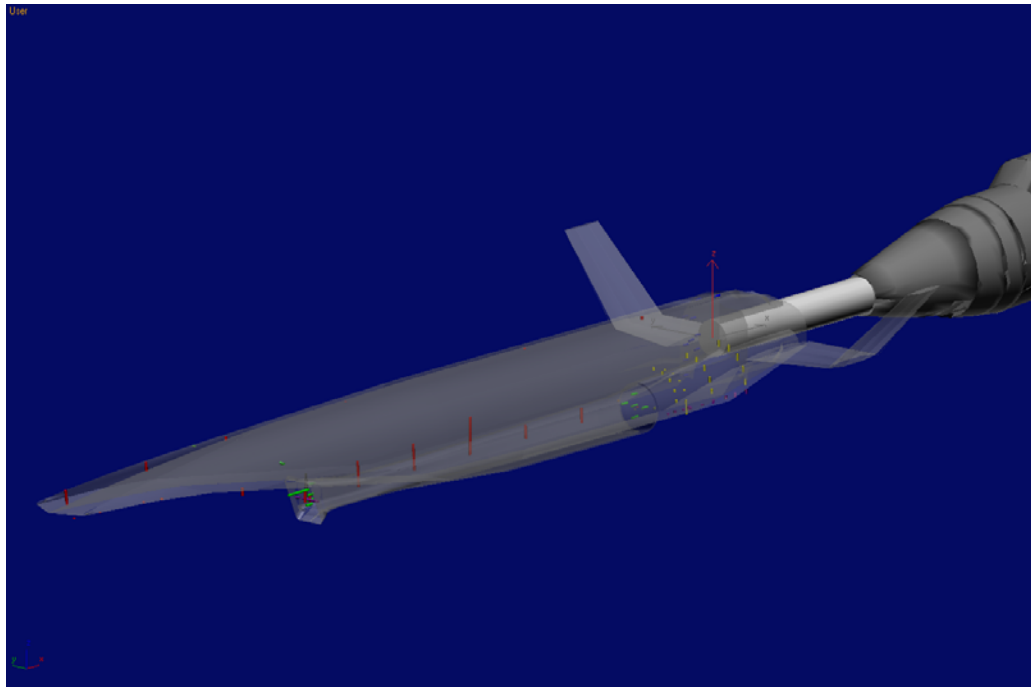


Figure 8. Example of combining pressure data with streaming video. Note that the pressure data shown here was derived from a sinusoidal input provided for testing purposes. Imagery of other configurations under actual test conditions are proprietary to particular companies.



**Figure 9. Interactive Virtual environment display with data pressure corresponding to Figure 6.
Note that this configuration has been highly altered to conceal proprietary nature of test configuration.**

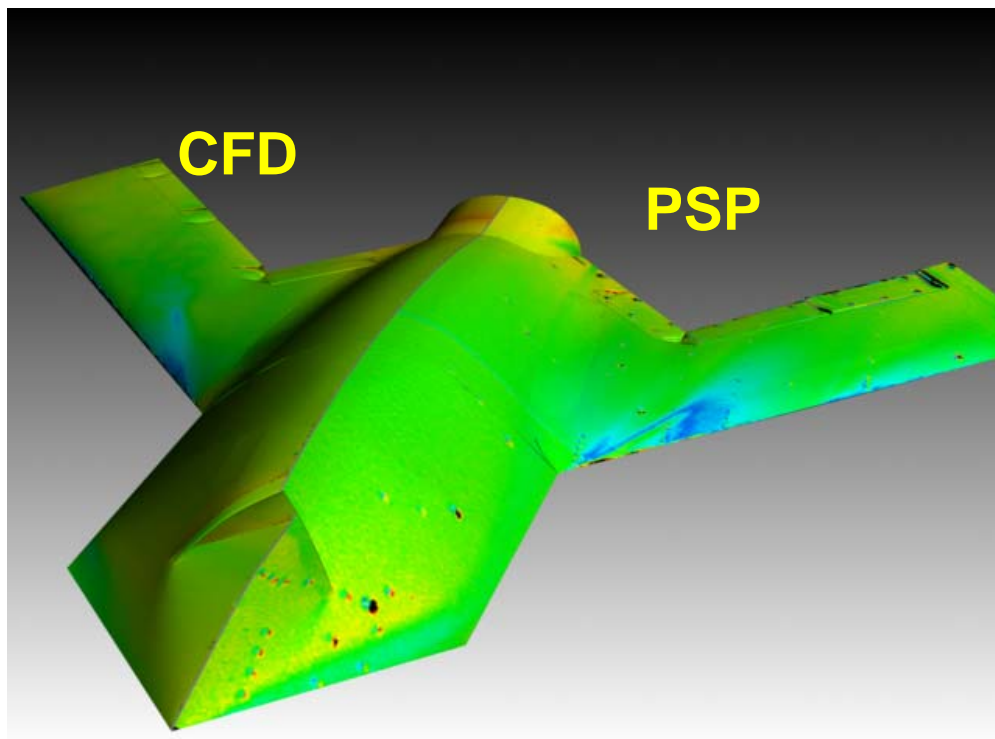


Figure 10. Comparison between Computational Fluid Dynamics (CFD) and Pressure Sensitive Paint (PSP) data rendered in ViDI environment.

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