Direction and Integration of Experimental Ground Test Capabilities and Computational Methods

Steven C. Dunn[1]
Jacobs Technology, Inc., Hampton, VA, 23681

This paper groups and summarizes the salient points and findings from two AIAA conference panels targeted at defining the direction, with associated key issues and recommendations, for the integration of experimental ground testing and computational methods. Each panel session utilized rapporteurs to capture comments from both the panel members and the audience. Additionally, a virtual panel of several experts were consulted between the two sessions and their comments were also captured. The information is organized into three time-based groupings, as well as by subject area. These panel sessions were designed to provide guidance to both researchers/developers and experimental/computational service providers in defining the future of ground testing, which will be inextricably integrated with the advancement of computational tools.

I.   Introduction

WIND tunnels have provided information for aeronautics researchers since before manned flight was achieved. Over the last several decades it has become possible, and for some flight regimes preferable, to utilize computationally modeled flow to gain understanding of flow phenomena. Since the 1980s, as computational capabilities improved, research and new designs typically used both experimental and computational tools, including for cross-validation of results, to reduce test costs and cycle times, and to support extrapolation of test data across flight envelopes[1]. There is a need to better define how these tools should be developed and utilized in an integrated manner going forward to support quality and efficiency requirements for research and development, as well as to provide guidance for investments in capabilities by stakeholders and decision makers. This scope cuts across all aeronautics work, including industry, government, academia, whether service providers or service users.

Two interactive panel sessions at American Institute of Aeronautics and Astronautics (AIAA) conferences were accomplished with a goal to bring subject matter experts together to provide information for a form of gap analysis assessment that would map out potential future directions for integrated experimental ground testing (GT) and computational fluid dynamics (CFD). This paper documents the findings from those two sessions, including additional insight provided by a ''virtual' panel between sessions. Since this information is intended to be used by subsequent roadmapping and planning efforts, the comments were organized into three timeframes – current state, near term (up to ten years out), and far term (ten to twenty plus years out).

II.   Background

A. Need

The AIAA Ground Testing Technical Committee (GTTC) has long identified the need to produce a work product that maps out the future of ground testing or, at least, identifies potential directions based on the forces from key variables. The panel sessions were designed to gain insights on these forces over time from subject matter experts as well as audience attendees. The objective of this panel series was to produce a vision over the next ten to twenty years on how the relationship between experimental ground testing and computational methods and the use of each form will evolve. The design was to gain insights from session 1 that would serve as an introduction to session 2. Introductory comments on the goals of these sessions included:
- The objective of these sessions is to provide a vision over the next ten to twenty years on how the relationship between (and the use of each form) experimental ground testing and computational

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[1] Senior Engineering Specialist, Hampton, VA, AIAA Associate Fellow and GTTC Chair.

American Institute of Aeronautics and Astronautics

methods will evolve. It aims to resolve whether more analysis will be more dominant or more experiments needed; or will some steady state exist?

- CFD and ground test landscapes are changing, sometimes quickly. Hence, their interaction will evolve as ever-better simulation of flight is achieved. Eliciting best practices, including the difficult areas of addressing interfaces (technology, organizational, skill requirements, cultural/personnel, et al.) are among the goals for this session.

- There is no doubt that our current facility structure is straining to remain relevant and reliable, so a goal of these sessions is to gain a greater perspective in how industry can continue to partner these two analysis methods into the vehicle development cycle in such a way that it is mutually beneficial to each discipline.

- The goals of the panel are to seek to share the value, deficit, and concerns in real experimental flight dynamics (EFD) with/ CFD integration among panelists and audience, which might lead to future collaborations between experimentalists and CFD researchers. Specifically, it is expected to discuss the substantial values in EFD/CFD integration, which cannot be attained only by EFD or CFD.

- Work towards the goal of assuring there will be a healthy and sustainable national wind tunnel infrastructure and testing capabilities with associated knowledge base for the support of United States defense goals.

- This is an opportunity to bring together researchers and managers representing both the experimental testing and computational simulation camps to discuss issues and develop strategies to address future research and development (R&D) needs of the aeronautics community while remaining cognizant of constrained budgetary realities.

- CFD is an important tool for integrated test and evaluation (IT&E) working in conjunction with ground test and flight test (FT) to provide engineering solutions. For ground testing, CFD is invaluable for determining facility effects on test results as well as effects associated with scale and other model approximation required for ground testing. CFD is also critical in designing efficient and effective test procedures and test facilities. Finally, CFD provides an important link between ground testing and flight testing. This session should identify gaps in the national computational analysis capability to perform IT&E and requirements for future computational capability and best practices to close these gaps.

B. Sessions

The first session was held at the AIAA Complex Aerospace Systems Exchange (CASE) in Los Angeles in August 2013 to define key issues, barriers to progress, and other concerns/problems. The session design and specifics, including a listing of the panelists, is provided as Appendix 1. Following the session, a work product resulting in key takeaways was produced and sent to a "virtual" panel for review and comment

The virtual panel was developed to add subject matter expertise to the work product – this expands the base beyond just those that could attend a particular conference. The virtual panelists and a description of the type of feedback received are provided as Appendix 2. An updated work product was prepared and used as the introduction for the second session.

The second session was held at the AIAA Science and Technology Forum and Exhibit (SciTech) in January 2014 at National Harbor, MD to build on the work and findings of the CASE session. This session began with a summary from CASE and the virtual panelists and then had an interactive panel session that focused more on further projections and 'world-class' solutions and best practices directed at the issues and takeaways generated by the first session. The session design and specifics, including a listing of the panelists, is provided as Appendix 3.

C. Purpose of this Paper

These panel sessions took place more than a year ago, with session 1 occurring more than two years ago. The environment that drove the need has, if anything, intensified. Political and corporate leadership need information upon which to base decisions that will affect the aerospace industry for decades going forward. It is the author's concern that unless a strong case can be made that ties specific research, development, test, and evaluation (RDT&E) capabilities to specific flying mission needs, decisions will often be based on short term budget requirements – very likely, capabilities will be unavailable when needed and research and product development risks will be considerably higher. The purpose of this paper is to provide information that describes the current state of experimental ground testing and CFD in providing services to aerospace researchers and developers and then to project forward potential future states and associated challenges and recommendations. The context and key points

from these panel sessions provide foundational information for ongoing efforts to develop action plans to coordinate investment and dependencies in existing and new experimental and computational modeling capabilities.

This information is not intended to be fully definitive, but to share the thinking of a collection of subject matter experts from various perspectives – service provider, service customer, and organization (industry, government, and academia). This collection of comments should be used as a type of checklist for topical consideration in future integrated GT and CFD planning efforts. The goal is to contribute to the body of knowledge on ground testing specifically and how the growing interdependence of ground testing and CFD will affect each discipline.

D. Organization of Results

Even though the comments were roughly organized by the questions that were asked, the subject matter often covered broader content. Once comments from the sessions were captured, they were and categorized in three types of groupings – service type, gap analysis categories and time frame.

Each comment was designated into a service type category and then grouped; the categories, with the abbreviations used for each comment and as ordered in each section, are:

- Customer, or capability user, perspective (Cust),
- Ground test (GT) capabilities and applications,
- Computational fluid dynamics (CFD) capabilities and applications,
- Flight testing and CFD integration (FT/CFD) capabilities and application and integration,
- GT and CFD integration (GT/CFD), and
- Environment/context/business (Env).

The gap analysis categories are:

- Current State
    - o Context/Environment,
    - o Capabilities/Services and Needs
- Gaps/Issues/Challenges, and
- Recommendations.

Even though the questions asked tried to drive to a vision of the future twenty or more years out, it was difficult to really project to more than a near-term extrapolation of current state. So comments within the gap analysis groups were assessed for timeframe and then separated into time-based categories:

- Current state,
- Near- to mid-term future state (mostly extrapolations of existing or recent technologies, timing based on extended funding, or efficiency and quality improvements to existing capabilities), and
- Mid-to far term future state (significant technology jumps, major advances).

Within each time group, information is grouped in the gap categories. The form of presentation of the material is with comments grouped in bullet/topic form. This promotes scanning for topics to be considered for inclusion in new efforts going forward.

III. Current State

A. Context/Environment

- (Cust) The question of how can we keep these facilities has been asked for 50 years. People are in the mode of protecting what they have. It's the wrong question. The real question is, what facilities do we need? The answer is, we need facilities that will best validate (predict?) flight.
- (GT) In the national debate on the retention of wind tunnels, wind tunnels are losing. Why is that?
    - o Despite having its basic capabilities understood and well-developed, being a validation tool for CFD (but appropriate metrics depend on the physics being probed), providing a basis for predicted

performance of the flight vehicle, performing as a risk reduction tactic from the standpoint of decreasing extra performance margin to be designed and built into the product, and being a producer of indisputable physics,

- o GT has the following noted deficiencies":
  - Extrapolating to flight is challenging
  - Generally can be very expensive for a high fidelity simulation.
  - Has a relatively long facility upgrade cycle time (2-20 years, depending on magnitude of upgrade.

- (CFD) CFD strengths allows one to obtain the "whole" flow solution;
  - o But they must be accredited for the particular application being examined.
  - o They also allow one to obtain what cannot be verified experimentally; although there are some things that can only be obtained experimentally.
- (CFD) Rapid maturation of CFD has caused a lot of challenges on how and when to best use it; its strengths and weaknesses, however, are rapidly changing.
  - o It is often used to define trade space for development and it provides inexpensive data for many configurations, however, they are vehicle dependent.
  - o Therefore, experimental validation is crucial, particularly for niche applications.
  - o Still, some have move away from CFD because they lack confidence in it.
- (CFD) In general, flight tests have shown that what we've done with CFD methods has been very accurate. Again, this is configuration or use dependent. For example, CFD is reliable for wing-tube configurations. Developing computational solutions to ground effects is still a challenge.
- (CFD) ALL data (CFD, test, analysis) must be as accurate as the problem demands. We can do loads and [transonic] cruise performance well now, once models are developed. When we have the models, we can then get solutions quickly. Yet, CFD isn't ready for rapid turn-around
- (CFD) No physical model is needed in CFD, therefore there is no manufacturing cost.
- (CFD) There have been significant advances in CFD tools in recent years.
  - o It can't handle highly integrated problems yet.
  - o This equates to more need for more and more complex experimental testing, for fewer data points, but with higher accuracy.
  - o Strengths and weaknesses of EFD (i.e., GT&FT) and CFD are almost opposites; therefore they complement each other.
  - o EFD, at present, is largely used for validation of a CFD method and for final design data.
  - o The wind tunnel element of EFD (i.e., GT) is used for validation now, but are moving away from developmental roles to characterization.
- (CFD) CFD is to the point that it can tell us if we have a problem in a test.
  - o Powered testing is an example where CFD was more correct than the wind tunnel.
  - o Our culture is that the wind tunnel is always correct compared to CFD.
  - o The truth is that the wind tunnel gives an answer and CFD gives an answer; these are just two different ways of simulating reality.
- (GT/CFD) CFD and wind tunnels work well together if you have the right skill sets (i.e., test, CFD, program aerodynamicists (performance, S&C, loads, flutter), researchers). CFD gets deltas, but is not so good for absolute numbers.
  - o Wind tunnels get absolute numbers (but caution that WT can be "absolutely" wrong too just like CFD).
  - o In CFD, we still tend to model grids like they are in wind tunnels.
- (GT/CFD) There are similarities between CFD and wind tunnels. Iteration between the two (or three, if FT is included) is often the preferred approach, but better coordination is highly desirable.
- (GT/CFD) Furthermore, what you get in a wind tunnel, flight test, or CFD solution is only a partial replication of truth (or reality). In a real sense, we have to get away from seeking total truth (is this data perfect in every respect) and figure out where we need duplication, replication or simulation and apply them in an integrated way.
- (GT/CFD) At present, we are doing more wind-tunnel testing and supplementing it with a lot of CFD.
  - o Program managers want reduced risk; engineers equate reduced risk with more data.
  - o However, a lot of data is generated that no one is looking at

- (GT/CFD) Both wind tunnels and CFD can produce bad (not useful) or good (useful) data, and the merger of the two will require combined expertise. How do you decide which to use? Which do you believe?
  - o Best practices say that the wind tunnel is a good starting point; with that baseline, apply CFD; then iterate back and forth.
  - o Basically, both wind tunnels and CFD are just data sources. You need the same fidelity of modeling of aircraft aerodynamics in both cases.
  - o The challenge is in knowing the right tool to choose for the task at hand.
  - o A common platform is needed for both types of testing.
- (GT/CFD) The use of wind tunnel data to validate CFD is now turning around to use CFD to help validate wind tunnels. For example, modeling the boundary condition on a slotted wind tunnel wall is very challenging, but is a more direct calculation of the slotted wall properties. Early CFD could supply one data point. Now we can almost use CFD to duplicate a wind tunnel test.
- (GT/CFD) Taking millions of data points is not the objective. Measures of quality and the ability to extract what we need from the data are what's required. In wind tunnel testing, you plan to take a certain amount of data and you typically decide ahead of time what data to take first. Previously, all CFD data were reviewed over weeks or months. Now it's impossible to store all the CFD data you can acquire, so you must decide in advance what data are needed. Let's not use the wind tunnel just for validation. These tools must be designed to reduce risk during the first flight.
- (GT/CFD) The question is, what tools need to be in place that support both disciplines and might be needed to support flight test as well? However, you can't run a complete CFD program during the early stages of a product development. But, with limited budgets, how do you decide between code and experimental investment?
- (GT/CFD) Many of the problems in hypersonic flow are turbulence and chemistry, added to already complex flows. We can't measure them experimentally. We must improve codes that exist now. Many of these are better than what we can measure. You can't operate in the necessary flight environments with our current facilities. In the United States we haven't built any major new hypersonic facilities in the last half-century. It's in the Mach 4, 5, and 6 range that compressibility and chemistry starts to count.
- (GT/CFD) Decisions are made to close or not build facilities because they look at rising GT annual costs and there's a perception that "we'll make do with CFD." However, as capabilities continue to advance, problems get more difficult. Therefore, both will be **needed** for a long time. Do we understand the true costs of computational capability? Some supercomputers are using 20 MW per day, much like some wind tunnels.
  - o CFD isn't causing the closure of ground test facilities. There are other reasons. We should stop talking CFD vs wind tunnels. They are complementary.
- (GT/CFD) We don't know how to calculate what we need to know. Therefore, we won't need more advanced computers (e.g., Quantum) until we do know. Until then, we will need experimental capabilities for the foreseeable future.
- (GT/CFD) What you get in a wind tunnel, flight test, or CFD solution is only a partial replication of truth (or reality) In a real sense we have to get away from seeking total truth (is this data perfect in every respect) and figure out where we need duplication, replication or simulation and apply them in an integrated way.
- (Env) In the '70s we could build large remotely controlled wind tunnel models. Now, neither AEDC nor anyone else can produce the large-scale models of the '70s.
- (Env) Over the years, wind tunnel infrastructure has decayed and its workforce knowledge-base has dwindled.
  - o Currently, we have less than 500 practitioners in the enterprise. We are losing our edge in test capabilities.
  - o We need to maintain the ability to do the fundamental set of things in ground test facilities that we do well now. We're having to teach things we used to do well to a new generation of wind tunnel testers. Skill is being loss due to both facility under-utilization and personnel retirement.
- (Env) The NASA/Glenn Research Center's 10' x 10' supersonic wind tunnel was the justification for shutting down AEDC's 16S; yet, how can we produce results comparable to AEDC's 16S in the 10' × 10'? Having the 10' X 10' and not having a well-defined and sufficient requirement for testing in large supersonic tunnels was the reason for the reliance on one wind tunnel. A better argument might be to see what kind of data cannot be obtained in the 10' X 10'.

- (Env) Now, what is the risk of not having 16S? A 10-foot square test section (i.e., the 10' × 10', NASA Glenn) is not large enough to test remote control models with jet interaction at high angles of attack.
    - In the absence of a large-scale facility, we must use smaller-scale models to avoid excessive wall effects: wall interference, turbulence, non-representative boundary layers.
- (Env) Someone has to manufacture the computer, pay for the software updates, operate and maintain the computer, and generate a grid.
- (Env) We struggle to maintain current and critical/necessary capabilities in a tight fiscal environment. In the end, we are driven by ROI and not actual need.
- (Env) The present environment for EFD/CFD is one of trying to maintain current and critical/necessary capabilities in a tight fiscal environment. Moreover, the pressing issue is how to enhance these capabilities. What can be afforded? What must be afforded? What drives the costs? These are primary questions.
- (Env) We don't know how to measure the infrastructure cost of CFD (high-end computers, personnel, etc.). What accounts most for this lack of understanding: accounting practice differences for CFD and GT, externally-driven accounting metrics (i.e., finance).
- (Env) We've gotten good at measuring the cost of ground test facilities. Cost structure drives behavior.
    - When the Unitary Plan was initiated in 1949, the government proposed to make facility usage free. Industry argued that we must charge for its use or it will have no value. "Free" facilities lead to overconsumption. They are used when they are not needed. Data are generated and never used.
- (Env) Many are pressured daily to maintain facilities without resources. Facilities on their own don't have day-to-day sustainment funds. Note that when one speaks of "facilities," this also include CFD; most budget people don't even know what CFD is. The government had an ownership role in capability throughout the '40s, '50s, and '60s; no longer!
- (Env) Are co-operative education programs (co-ops) being used as extensively as they once were or should it be revived? Co-op is done at Glenn. Raytheon has an excellent internship program. Internships are necessary, but mentors are needed to foster the interns' growth, so it won't be a waste of time.

B. Capabilities/Services and Needs

- (Cust) In EFD (i.e., GT&FT) or CFD testing, most of what the commercial companies do is "fill out" the corners of the flight envelope versus R&D. There is a cultural gap between the ultimate user of the data and those who provide it; it is necessary to understand customer needs.
- (Cust) Customer accuracy requirements are becoming more stringent.
- (Cust) From an industry perspective, cost and schedule are the two big hitters. Our main limitations are Return-on-Investment (ROI) - Industry has a short horizon; rates are set annually; and Capital planning - payback should be over some specified number of years.
- (Cust) Test data for increasingly challenging flight envelopes can drive many program decisions. Cost and schedule are important for all customers. For example:
    - Tube-wing production configurations, large and small commercial and military transports:
        - a. Configuration trades and entire flight envelope data base.
    - Defense articles: fighters, missiles/bombs/stores, UAV's. Large flight envelope (in Mach, α, and β).
        - a. Subsonic through hypersonic flight article requirements.
        - b. Blow-down testing versus "higher fidelity" continuous flow data measurements.
        - c. Associated test risks for each test scenario.
    - Technology and R&D for the above and for unconventional configurations (blended wing-body, Natural Laminar Flow (NLF) and Hybrid Laminar-Flow Control (HLFC), X-wing, etc.)
- (Cust) Why are we doing more wind-tunnel testing? (F-22, 40,000 hours; F-35, 50,000 hours)?
    - Program managers want reduced risk; engineers equate reduced risk with more data.
- (Cust) If the wind tunnel is not there, we must build extra margin into the vehicle at increased cost and risk.
    - In some cases, yes. In other cases, additional risk in the vehicle is not acceptable and we would have to determine we can no longer develop that type of vehicle
- (Cust) In hypersonics, we're drawn to a core set of facilities based on our vision vehicles.
- (GT) Developers of missiles, high-speed aircraft, and space access/return vehicles are more dependent on wind tunnels than CFD because of the requirement to maneuver and operate at the edges of the envelope…the edge of stall.

- (GT) Hypersonic facilities tend to be little utilized.
  - Some of our capabilities today are at capacity.
- (GT) Rapid prototyping capability for non-load-bearing parts is excellent
- (CFD) You can get whole properties when you conduct CFD.
  - No physical model is needed in CFD, therefore there is no manufacturing cost. (But someone has to manufacture the computer, pay for the software updates, operate and maintain the computer, and build a grid.
- (CFD) We move away from CFD because we lack confidence in it.
  - Strength: the entire flow solution is in hand, including non-verifiable information.
  - Experimental validation is crucial, particularly for niche applications. What are the metrics?
- (CFD) CFD isn't yet ready for rapid turn-around
- (CFD) There have been significant advances in CFD tools in recent years.
  - It can't handle highly integrated problems yet.
  - This equates to more need for more and more complex experimental testing, for fewer data points, but with higher accuracy.
- (CFD) In CFD, we still tend to model grids like they are in wind tunnels
- (CFD) Presently we do not replicate all the physics. CFD quality gets better whenever we understand more and approximate less.
- (FT/CFD) Flight test has shown that what we've done with computational methods has been very accurate. Again this is configuration or use dependent
- (GT/CFD) There are totally different requirements for tools for developing an aero database from those needed for research. However, both require a healthy mix of both ground testing and CFD.
- (GT/CFD) Strengths and weaknesses of EFD and CFD are almost opposites; therefore they complement each other
- (GT/CFD) EFD is largely used for validation of a CFD method and for final design data
- (GT/CFD) Wind tunnels are used for validation now.
  - Wind tunnels are moving away from developmental roles to characterization
- (GT/CFD) It is interesting that the expectation is that CFD models should be ready in one day. We don't expect the same for EFD models.
  - Be careful. We expect that rapid prototyping, metal printers and other additive techniques might move us toward test articles built very quickly. While the past has certainly involved long lead time for complicated test articles, wouldn't it be ironic if we ended up taking longer for a computation than a test?
- (GT/CFD) Both wind tunnels and CFD can produce bad (not useful? or good/useful?) data, and both require expertise.
  - The merger of the two will require combined expertise
- (GT/CFD) How much would you trust the wind tunnel at extreme conditions?
  - The wind tunnel is a good starting point; with that baseline, apply CFD; then iterate back and forth
- (GT/CFD) We use multiple wind tunnels and multiple CFD tools; the challenge is in knowing the right tool to choose for the task at hand.

C. Current and Near-Term Gaps, Issues, and Challenges

- (GT) The strengths of ground testing (GT) are that its measurements are finite and its physics are well defined and irrefutable, except that it's in a wind tunnel.
  - Wind tunnels, flights, and computations are physics based but not necessarily physics-perfect.
  - We estimate in each, make approximations and only replicate some physics in all three methods.
  - The difficulty is in extrapolating these results to actual flight conditions.
- (GT) We are losing our edge in test capabilities.
  - We need to maintain the ability to do the fundamental set of things in ground test facilities that we do well now.
  - We're having to teach things we used to do well to a new generation of wind tunnel testers.
  - Skill loss due to both facility under-utilization and personnel retirement

- (GT/CFD) Experimental GT is reliable but is limited by capabilities and techniques (e.g., walls, model support) and lacks detail. It could be said that CFD have the same limitations since it is validated by test. But, GT cost is higher than computational fluid dynamics (CFD).

D. Recommendations

- (GT/CFD) A Vision 2030 plan for the next 15 to 20 years.
    - o Things typically not done well with GT, so targeted by CFD.
    - o Critical flow phenomena:
        - Icing
        - Turbo-machinery noise
        - Rotary aerodynamics structural flows
        - Ablative aero-thermodynamics
    - o Failure to adequately validate and verify computational models is concern here

IV. Near- to Mid-Term Projections

A. Near- to Mid-term Future State

- (GT) Wind tunnels will be needed for the foreseeable future. Investments in wind tunnels will allow the U.S. the protection and security that is needed.
    - o Ground testing is going to have to continue to do the legacy things it does well now: e.g., measure forces, moments, pressures, and temperatures.
- (CFD) As we move from a conventional tube plus wing to blended bodies, there is less confidence in CFD.
    - o Aircraft configurations are becoming highly integrated (e.g., blended wing-body).
    - o The lower speed flight regime is seeing what the high-speed flight folks have worked for years.
    - o Multidisciplinary solutions with chemistry and analytic solutions that are impossible without rigorous validation information.
- (CFD) It is believed that Hybrid Large Eddy Simulation (LES) / Reynolds-Averaged Navier–Stokes (RANS) models will get us there. Navier-Stokes solutions are often needed. But, basically, we have no fundamental understanding of turbulence.
- (GT/CFD) Future development will rely on continued development of CFD tools and techniques. In the end, however, we must have experimental verification and validation of these tools.
- (GT/CFD) It is reflected in the list of arguments that as long as there are models embedded in the CFD (for turbulence, transition, separation…), experiments will have to be performed to verify the models in their range of applicability. But it also means that the CFD can be employed to reduce experimental uncertainty and constraints. In a manner analogous to wind tunnel wall corrections, other imperfections of WT testing can be quantified by means of CFD. In addition to that, flow field quantities can be obtained as a function of measured parameters. This will cause new and improved measurement techniques to come along, by enabling verification of the measurement techniques instead of verifying codes.
- (GT/CFD) There are two tracks:
    - o Merge CFD and experiments for knowledge capture for things CFD can already do.
        - High Reynolds number transonic aircraft CFD modeling wasn't possible 20 years ago.
        - Still need experimental facilities to support this.
    - o Where CFD can't do the job, we need experimental facilities to validate designs.
        - Must understand your boundary conditions exactly
- (GT/CFD) There could be three tracks:
    - o Aerodynamicists using both CFD and experimental capabilities
    - o Experimental specialists
    - o CFD specialists
- (Env) Many feel that DoD and NASA need to remember their traditional roles as times continue to be tough.
    - o That NASA should invest more in developing advanced wind tunnel measurement capabilities since that is consistent with their research and development charter; particularly being in the forefront in developing test techniques.

o That DoD should invest more in maintaining the quality of data in existing wind tunnels since that is consistent with their evaluation and development charter and continuing to lead in accurate pressure and force-&-moment measurements.

B. Issues

- (GT) Improvements are needed in wind tunnels:
    o Efficiency
    o Rapid prototyping
    o New measurement techniques
        ▪ Unsteady flow measurements
        ▪ Skin-friction measurements
        ▪ Non-intrusive: Pressure sensitive paint and particle image velocimetry
- (GT) Over the years wind tunnel infrastructure has decayed and the workforce knowledge base has dwindled.
    o 16S is a prime example of loss of capability. Who's next?
- (GT) Running wind tunnel tests is the quickest way to fill in a database, especially if you want to capture control (effector) power. You can get a lot of data quickly in a tunnel. Modeling all the different flap settings takes forever and rerunning solutions for each setting can take more computer time than just running a few cases to fill in a polar.
- (GT) We need [wind tunnel] models to enable us to treat flows inside scramjet engines as close to reality as possible.
- (GT) We are running the risk of losing people with experimental expertise because we are doing less testing
- (CFD) Rapid grid generation is a challenge in CFD. It will be a big focus in the next 10 to 15 years.
    o Productivity is currently limited by long cycle time for grid generation (configuration-dependent); computing time for complex configurations. In CFD solutions, 60% to 80% of the time is needed to get grids together; the rest is running the solution and finalizing the results.
    o We want rapid / instantaneous grid generation.
    o We need more of a real-time capability; several solutions per day vs. overnight or a weekend.
- (CFD) Rapid maturation of CFD has caused a lot of challenges on how and when to best use it.
    o Often used to define trade space for development.
    o Inexpensive data for many configurations.
    o Strengths and weaknesses are rapidly changing.
        ▪ They are vehicle dependent.
        ▪ No model manufacturing costs (traded perhaps for grid generation costs).
- (CFD) Running Detached Eddy Simulation, Delayed Detached Eddy Simulation, Large Eddy Simulation, or Direct Numerical Simulation would be WAY too cost prohibitive to fill in an entire database, but is being asked of us all the time. But many times we still don't know how well the codes are doing because we just have not validated/calibrated/verified the methods.
- (GT/CFD) There are barriers to effecting improvements.
    o True integration of ground test and CFD requires real-time fabrication of a wind-tunnel model to validate a CFD solution.
    o We'll always need some form of experimentation to validate the models we develop.
- (GT/CFD) Ten years ago we needed a PhD to do CFD. That's changing now. Still need PhD for modeling, but CFD is becoming easier to use. Concepts are still pretty foreign to non-CFD'rs. Experimentalists are trainable if it's not too hard.
    o Can CFD'rs be trained to use experimental capabilities? This is questionable. The field is too specialized to have them set up a test and run it.
- (GT/CFD) Experimental Fluid Dynamics (EFD) is reliable but is limited by capabilities and techniques (e.g., walls, model support) and lacks detail.
    o Comment: Might CFD have the same limitations since it is validated by test (or complete understanding of physics)?
    o Cost is higher than computational fluid dynamics.
- (GT/CFD) How do you decide which (wind tunnels or CFD) to use? Which do you believe?
- (GT/CFD) We use multiple wind tunnels and multiple CFD tools; the challenge is in knowing the right tool to choose for the task at hand

- (GT/CFD) There are barriers to effecting improvements.
    - True integration of ground test and CFD requires real-time fabrication of a wind-tunnel model to validate a CFD solution.
    - Also requires a change in customer paradigm.
    - Loss of skill sets: We are losing, or have lost, a lot of expertise.
        - Must relearn each design cycle.
    - We are driven by return on investment and bean counters; not actual need.
- (Env) How do we make our wind tunnels pay for themselves?
    - Low-speed tunnels are pretty busy; high-speed tunnels are not.
    - It should be noted that the AEDC high-speed wind tunnels and some in private industry are operating near capacity today.
- (Env) Workforce recruitment, training and retention is a big issue.
- (Env) It is difficult for ground test to compare with "free" computer time and three-year cycle computer systems that are refreshed for much improved capability. Similar periodic upgrades are needed for ground test facilities.
- (Env) There is a behavioral issue with free wind tunnels: people take all the time they want, not what they need without discipline. If cost is not the discipline maker, what is a recommended alternative?
- (Env) We have to overcome a 30-year mentality of wind tunnels. But we lack a vision for the funding of our facilities. Should we run these facilities as a business? Some believe that this is not advantageous. What is the ROI? And for whom?
- (Env) If a facility isn't used, it is at risk of closure.
- (Env) Our main limitations:
    - Return-on-investment: We have a short horizon. Rates are set annually.
    - Capital planning: payback should be over some specified number of years.
- (Env) We don't know how to measure the infrastructure cost of CFD (high-end computers, personnel, etc.).
    - Why not?
    - Accounting practice differences for CFD and GT. Accounting metrics are externally (i.e., finance) driven.
- (Env) We lack a vision for the funding of our facilities.
    - The lack of funding is a limiter.
- (Env) Do we understand the true costs of computational capability?
    - Some supercomputers are using 20 MW per day, much like some wind tunnels.
- (Env) We have no leadership to move us into new areas.
    - What do we do?
    - What do we want with the resources we have?

C. Recommendations

- (Cust)Aerodynamicists must have feet in both camps and work interfaces
    - Much harder
- (GT) (Cust) (Env)The value of wind tunnels for weapon systems should be measured by the quality of flight systems we can produce rather than cost.
    - For example, testing the interaction of fins and jets requires large-scale supersonic capability. This is why the inactivation of 16S has been a big loss to the missile community.
    - In making this statement, we need to make sure we can communicate in what ways the missile community has suffered loss. This is not apparent to the decision makers and the case for the high cost of reactivation and sustainment has not been made yet.
- (GT) The challenge of aerodynamic testing is powered models. Techniques are needed to help us handle these situations.
- (GT) We must develop test and measurement techniques that go beyond what pressure-sensitive paint has been promising for the past 10 years.
- (GT) A large-scale (16-ft square test section) (AEDC/16S) supersonic (hypersonic?) wind tunnel testing capability is needed for the development of expanded missile defense vehicles.
    - If the wind tunnel is not there, we must build extra margin into the vehicle at increased cost and risk.

- o If additional risk in the vehicle is not acceptable, we may have to determine if we can no longer develop that type of vehicle.
- (GT) Clean up the inefficiencies in wind tunnels.
  - o Support short cycle times early in a program
- (GT) Realization: We must analyze the wind tunnel in its environment with all interferences in order to understand it.
- (CFD) What kinds of things would improve code development if we could measure them? Corner flows; wind tunnel turbulence; boundary layers.
  - o All are becoming more critical as we start to operate near the edges of the envelope.
  - o Off-body measurements could make a big difference.
  - o Quick early looks for sorting configurations, especially unconventional ones.
- (CFD) CFD should be used to understand the trade space.
  - o Trade studies can be validated in blow-down wind tunnels where testing is relatively inexpensive compared to continuous flow tunnels.
  - o One can obtain quick, cheap data for a large number of configurations early, with lots of high quality data from continuous flow tunnels coming later.
  - o It is noted that data from blow-down wind tunnels have matched data quality of continuous tunnels.
  - o The comment is valid in that we need to use inexpensive (never cheap) data sources early-on when tolerance for uncertainty is highest, then switch to more accurate data sources (and yes usually more expensive) when tolerance for uncertainty is low.
- (CFD) Missing in computational capability is a way to get from identifying a problem, to its solution.
  - o Need capabilities for both computationalists and aerodynamicists to understand each step of the process; must not expect each participant to understand every detail of developing the information.
  - o Need to have people from both worlds (experimental and theory) available to the aerodynamicist. We obtain much data from experiments, and orders of magnitude more from CFD.
  - o Need "data reductionists" and to design software to handle data.
- (GT/CFD) As increasing cost means fewer experiments, better coordination must occur between ground test or flight test and CFD.
  - o Model assumptions must be the same.
  - o Potential flight test experiments must be part of these discussions.
  - o We don't know how to measure the infrastructure cost of CFD.
- (GT/CFD) CFD specialists need to understand enough about ground testing to be able to go into that data and get what they need.
  - o We need CFD practitioners on the test shift (EFD) and vice-versa. That way, everyone will understand what the issues are.
  - o It's not preferable to outsource operations of facilities to people who run them like production lines. If you don't, you lose the ability to integrate experts in CFD.
- (GT/CFD) New engineers should be trained across the disciplines of ground (and flight) testing and CFD. This provides a common platform from which the disciplines can operate.
  - o An "integrated" engineer will be able to decide which tool is most suited to the problem he is trying to solve; be more of a systems engineer.
- (GT/CFD) More hours in test facilities is not the solution.
  - o Need more information, not more data.
  - o Need a computational capability to back up the measurements.
- (GT/CFD) We are running the risk of losing people with experimental expertise because we are doing less testing. Many advances are occurring at colleges and universities. Need to make CFD and experimental one community. Follow-on training is important after entering this community. In trying to produce flight vehicles, both experimentalists on one side and CFD'rs on the other are feeling restricted in identifying characteristics. People need to know both techniques to a minimum level.
- (GT/CFD) We need to re-emphasize communications between our two communities.
  - o Cultural biases: experimentalists try to match CFD and are skeptical of test data, and CFD aero types believe experimental data and tweak codes to match measurements. Can we cross-train and cross-fertilize these disparate (at this time) experiences?

- (GT/CFD) For research, we need to use CFD to acquire data that is pretty hard to obtain from the tunnels, but we need the wind tunnel tests to provide us the data to verify or validate the CFD.
- (Env) There must be a way of making facilities available in a pre-paid manner.
    - Some (our national infrastructure) are pre-paid. We pay for about 60% of our infrastructure up front and charge users the remaining direct charges.
    - This also depends on who is testing. For example when the federal government invests in a facility, private industry cannot use that investment since it would be an unfair competitive advantage.
    - We can look at funding mechanisms to do this however based on need. Still, you must control facilities' use.
- (Env) Industry and government should bite the bullet and pay to keep these [EFD/CFD?] facilities open and free for us to use. If you have more demand for test time than you have time available, let management decide who gets the time.
- (Env) We should not let any wind tunnel capability go away simply because it is unused. If it is unused, we need to discover why it is unused
- (Env) A national will and leadership is needed to sustain funding to get young people into an area like aerodynamics. A course of study in experimentation (wind tunnel testing) is needed. For example, Raytheon has internal EFD courses, but the wind tunnel course isn't hands-on. Some of these are also online courses and lunch-and-learn. Need to get experts in the field to participate in these courses while they are still around.
- (Env) Need to define paths for people to follow in developing these areas:
    - Manage experienced people.
    - Organizations are leaned out.
    - Put young people with older, smart people.
- (Env) We have training regimens, but it takes years of experience to become an expert. It's difficult enough without tying in another discipline. Need to look at best practices of organizations like NASA and Boeing.
- (Env) The education system is becoming much more multi-disciplinary. Need young people with the ability to see the big picture. Meaningful work is important. Should not just have young people tracking down drawings, etc. The work must interest them.

V. Long-Term Projections

A. Long-term Future State

- (Cust) We will have to get better because our competitors will continue to get better.
    - Competition is our driver
- (CFD) CFD 2030 predicts that turbulence modeling can't be mastered in the next 20 to 30 years when computers are expected to become more capable.
    - Complex CFD solutions require a lot of computing time for high-fidelity results.
    - Perhaps in 20 to 40 years CFD will be able to provide reasonable Reynolds number solutions in reasonable computational time.
    - Our definitions of reasonable change every year. 20 to 40 years ago, we would have thought today's solutions were "reasonable"
- (CFD) We will have to solve turbulence in order to eliminate the need to validate CFD.
    - Wind tunnels will not be needed when we can get realistic Reynolds number data in realistic (hours) timeframe w/o any models imbedded – a true physics-based model.
- (CFD) As time goes on, we'll swing toward CFD for early data. This may drive wind tunnel closures based on the percentage of CFD vs. wind tunnel data in the development process.
    - 20% to 30% of data from wind tunnels should not translate to percentage of wind tunnel capacity to be retained.
    - We as an enterprise need to understand the value of validated CFD and figure that in our planning for capacity-based test services.
    - This means we have to be real good at predicting and real honest in our assessment.
- (CFD) Rapid grid generation is a challenge in CFD
    - It will be a big focus in the next 10 to 15 years

- o We want rapid / instantaneous grid generation
  - o Productivity is limited by long cycle time for grid generation (configuration-dependent); computing time for complex configurations.
- (CFD) CFD 2030: Turbulence modeling can't be mastered in the next 20 to 30 years.
  - o Computers will become more capable.
- (CFD) How good is good enough?
  - o When we can generate grids quickly and generate turbulence models in a day or so
- (CFD) Perhaps in 50 years, we won't need wind tunnels to validate CFD results.
  - o Perhaps in 50 years CFD will be replaced by something else
- (CFD) When will CFD codes not need experimental validation?
  - o Perhaps when they perfectly include all the physics at a scientific level.
- (CFD) We will have to solve turbulence in order to eliminate the need to validate CFD.
  - o It will never happen. [but . . . never say never)
- (GT/CFD) As long as we innovate and create, we'll always need the ability to validate CFD solutions in wind tunnels.
- (GT/CFD) Higher-fidelity CFD will require higher-fidelity experimentation
- (GT/CFD) We'll always need some form of experimentation to validate the models we develop
- (GT/CFD) The few experiments we continue to do need to be coordinated with the computational world.
  - o Model assumptions must be the same.
  - o Comment: Great point. Often these are not the same. I have some great examples of simplifications to hardware (for ease of gridding) that transpired. They resulted in a mismatch.

B. Issues

- (CFD) Turbulence modeling is a pacing item, and is still not well understood.
  - o We are far from automatic grid generation.
  - o It is very case-dependent
- (CFD) A major weakness of CFD is in turbulence modeling – you get a different answer depending on the flow conditions.
  - o Yet, some test facilities cannot replicate the turbulence found in nature as well; or answer such questions as when does the flow separate or when does it transition?
  - o While these situations are improving, turbulence modeling is a pacing item, and is still not well understood; but, again, this is very case dependent.

C. Recommendations

- (Cust) Use specific facilities or CFD capabilities to reduce risk for the vehicles produced and the people [i.e., passengers] in them.
  - o Need a test facility in the U.S. to be able to match the flight Reynolds number.
  - o Need a test method well-enough validated to provide confidence in the result.
  - o Need to gain confidence that the program can be taken to flight test and perform as expected.
- (GT/CFD) EFD and CFD tools must be developed in tandem.
  - o Need more understanding of basic phenomena [first], which can be provided experimentally.
  - o Need more stringent experimental measurement tools to be able to evaluate computational results.
  - o Need capabilities to measure things we couldn't measure before and help us gain a better understanding of basic phenomena.
  - o Need to be able to validate new CFD tools.
  - o Need diagnostics internal to the model vs outside because we can't predict the interaction of the wing-body juncture.
  - o Need more than just point verification

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- (GT/CFD) Whether experimental or CFD, the concern is how long it takes to produce information for flight prediction; need to produce knowledge, not data. Whether experimental or CFD, the developer must know his customer's accuracy requirements which are becoming more stringent in many ways; e.g., cruise and pitching moment considerations.
- (GT/CFD) There is a lack of effective coordination between the EFD and CFD communities. There is stove-piping and competition for funding. Need customer "pull" to develop capability; however, the customer doesn't want to pay for it.
- (GT/CFD) What are the most important things to validate? We can't measure everything. Need CFD to extrapolate Reynolds number. We look for parallel measurements to compare EFD and CFD in meaningful ways. For example, we extrapolate wakes, etc., to get comparisons.
- (GT/CFD) Need to have effective coordination between EFD and CFD; common criteria are required. Weaknesses and strengths are almost opposites between EFD and CFD.
- (Env) We should use what dollars we have to make what we have a little better. We need a program or a clear direction to go to tell us what facility capabilities we need to invest in.
- (Env) (Cust) What facilities are needed in the decision process? When we switched from reimbursable budget authority (RBA) to direct budget authority (DBA), there was degradation. Government should fund capabilities for industry to use. If you don't have facilities so you can test to see what you don't know, you won't realize what problems you are missing. For example, we need models to enable us to treat flows inside scramjet engines as close to reality as possible

VI. Summary of Key Points

A. Current/Near-Term

- Experimental Fluid Dynamics (EFD) and CFD have complementary roles in the characterization of aerospace systems, and there are some blurred areas of overlap.
- Sustainment of EFD infrastructure is a challenge in today's funding environment – some form of an enterprise solution that maintains critical capability and sustains it properly is needed. Discussions on how to pay for the sustainment of capability need to continue.
- We must overcome the mentality that little-used wind tunnels should be closed. There needs to be a value proposition that allows for low usage but critical infrastructure along with a way to properly sustain (or replace it). The true value of wind tunnel testing is not proportional to how much they are being used, but rather to the reduced risk of developing aeronautical products with advanced capabilities. National investments should be made on what is needed for national defense and not what is expected to be used on a frequent basis.
  - "I don't think documenting the regret about certain facilities having been declared obsolete (AEDC S16) is productive. Rather, it is striking that the discussion of solid criteria for obsolescence and future need is rather thin, although the convincing argument that it is not the rate of occupation of a facility but the added value it provides to a product is recorded."
- ***KEY IDEA****: We are concerned with the metrics of comparing experimental and CFD results, but the big challenge is to predict what's going on in flight.*
- ***KEY IDEA****: Need to concentrate investments on facilities for production capability to stay ahead of the rest of the world.*
- ***KEY IDEA****: It is a problem that we are currently only trying to make what we already do less expensive.*
- ***KEY IDEA****: Whether it is experimental or computational, it is just a tool*

B. Near- to Mid-Term

- Individual engineers need to work both CFD and EFD for the industry to make greater progress toward advancing the state of the art. The "stove-piping" needs to be eliminated.

- o We need to train engineers to understand both EFD and CFD so that better decisions can be made as to which tool to use at any given time. Attention needs to be given to the future testing workforce. Efforts to increase workforce technical ability through efforts like STEM and training alone have proven unconnected and unreliable. A robust and directed program to equip, train and technically nourish the workforce is required for a vibrant and impactful enterprise. We need to pass graybeards' knowledge to the young workforce.
  - o On the other hand, "we need specialists to take full advantage of the possibilities of the developing technologies. Only specialists in specific technologies can produce the result needed at the current stage of maturity in aeronautics. One doesn't become a specialist on a part-time basis."
  - o "What we also need, in addition to the specialists, are people at responsible levels who can understand, combine and synthesize the different streams of information."
- *__KEY IDEA__: What was missing from the whole discussion was the development of measurement techniques and data acquisition. . . ; it could be extrapolated that a new specialty is evolving in addition to the numeriscist and the experimentalist, that of the __data reductionist__. (NOTE: The rationale was provided that data mining or data extraction is needed to drive cost down and quality up.)*
- *__KEY IDEA__: Level the playing field between disciplines on tool cost and provide a means of allocating sometimes scarce (and costly) tool availability.*
- *__KEY IDEA__: The process of handling data and converting it to knowledge is critical.*
- *__KEY IDEA__: There is a need to educate and train engineers to be competent in both EFD and CFD.*
- *__KEY IDEA__: The driving consideration is for risk reduction in flight, even if the GT/CFD capability is used only once.*

C. Mid- to Long-Term

- EFD (e.g., wind tunnels) will be needed for a long time to come to validate CFD solutions and to provide data where CFD can't.
- The primary CFD limitations (turbulence models and grid generation) are well-known and "won't be resolved in the next several decades, or maybe ever".
- *__KEY IDEA__: Need methods that will help get the product to market faster.*
- *__KEY IDEA__: Need to develop and advance experimental capabilities that enable data acquisition for use in CFD to assist better modeling for better predictions.*
- *__KEY IDEA__: Need to stop thinking of two separate communities (i.e., EFD and CFD) and think in terms of a "prediction community." Put the needs on the table and then decide what investments are needed. In most cases we will need a joint response from the computational and experimental communities working the problem together.*
- *__KEY IDEA__: Do not overestimate CFD and therefore overlook the continued need for experimental capability. This would risk premature facility closure and it would lead to unrealistic expectations for CFD.*
- *__KEY IDEA__: We can talk about all the things we need to do things, but there is no commitment to a national capability. Without the commitment, we're stuck in the cycle of determining what to divest ourselves of. Unfortunately, this country lacks then necessary leadership needed in this area.*

VII. Closing

   This paper presents a summary of topics and opinions about the current state and the direction and integration of ground testing and CFD from two panel sessions and one virtual review panel. This includes perspectives from different organizations, from primarily computational and primarily experimental ground test service providers, and capability customers. The discussion from the sessions was wide-ranging as the discussion was guided to identify the current state of services and to project out ten to twenty years to describe what those services might look like along with the challenges and how to meet those challenges to achieve the future state. There are clearly many aspects to the work that needs to be accomplished in order for GT and CFD test services to be ready for new research and new customer product development. And there are many opinions in how to do that work.

Topics, all evolving over time, included:
- Customer needs for capabilities
- State of experimental ground testing capabilities
  - Challenging budgets have led to loss of capabilities and degradation of other capabilities
  - Usage for some capabilities is down, even as others are up – why?
  - There is and will be a continuing need for better measurement techniques
- State of CFD capabilities
  - Capabilities are improving and have broadening applications
  - Significant quality and design issues remain, especially for assessing geometries and mission needs beyond transonic cruise for a tube and wing design
  - The ability to model turbulent flow is crucial, very difficult, and the timeframe to accomplish is likely decades
- GT and CFD integration
  - Customer tool selection criteria
  - How GT and CFD capabilities can be complementary
  - The need for integration of the communities and integrated test design
  - Use of experimental capabilities to validate computational modeling
- Environmental and business factors
  - Differences in cost accounting for GT and CFD
  - Challenges of acquiring and sustaining qualified staff
  - Who pays for capability sustainment and investments
  - Taking a national perspective of capabilities (rather than parochial).

There remains a clear need for a national effort to develop an integrated roadmap that provides both a vision paired with an adjustable tactical plan for sustainment and investment in experimental and computational capabilities that will meet the future needs of both government and industry, from foundational research to finished product. The topical information in this paper should serve as a form of checklist for that future effort to ensure the many elements in the RDT&E process are considered for research and product development in terms of technical risk management and potential defect migration, cycle times, and costs.

APPENDIX 1

Logistics of Panel Session 1

Session Title: **Direction and Integration of Experimental Ground Test Capabilities and Computational Methods, Part I**

Subject: Provide a vision over the next ten to twenty years on how the relationship between (and the use of each form) experimental ground testing and computational methods will evolve. Will more analysis be more dominant or more experiments needed; or will some steady state exist?

This is part one of a two-part series. Session one will be used to establish the context, issues, problems, barriers, and roadblocks involved. This information will be used to formulate a basis for the development of solutions and "great ideas" during Part 2.

Venue: Hyatt Regency Century Plaza, Los Angeles, CA

Date: August 13th, 2013

Panelists:

1. Mr. Alex Krynytzky, Aerodynamics/Noise/Propulsion Laboratories, The Boeing Company, Seattle, WA

2. Mr. Shigeya Watanabe, Director, Wind Tunnel Technology Center, Japan Aerospace Exploration Agency

3. Mr. Tom Wayman, Core Engineering Group Head in Applied Aerodynamics at Gulfstream Aerospace Corporation in Savannah, GA

4. Dr. Rubén Del Rosario, Manager of the Fixed Wing Project in NASA's Fundamental Aeronautics Program

5. Dr. Edward Marquart, Engineering Fellow on the staff of the Aerodynamics Department in the Engineering Directorate at Raytheon Missile Systems, Tucson, AZ

Facilitators (and Session Co-Chairs): Dr. Steven Dunn, Jacobs and Mr. George Sydnor, NASA

Discussion Topics:
Topic 1: Context, relative strengths and weaknesses -- Where are we now?
* Is there an understanding of the roles of CFD and GT? Is it different for Science and Technology (research) vs. Developmental Test & Evaluation (production) applications?
* What is the current state of the art?
    o What is strong and weak in each?
    o Quantity versus quality?
    o How do they work together?
    o How will this be different in 10 years? 20 years?
* What are the primary simulation issues with CFD? with GT?

Topic 2: Future development and trajectories -- Where do we need to be?
* Define possible improvements of these methods in support of the RDT&E process. Can you include a timeframe?
* How are business models/practices affected? (work migrating to computation while ground test facilities calculate rates based on occupancy, computer time seen as free -- when borne by others)
* What are barriers/problems to effecting these improvements?
* How good is good enough? (Data quality/quantity, analytical grid sizing, . . .)
* When will CFD codes not need experimental validation?

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Topic 3: Futuristic integration and collaboration – how do we get there?

- Presumably, work will be shifting from GT to CFD going forward -- how do we need to be preparing for and embracing the shift?
- This shift has already taken place. It is never (nor do I think ever will be) complete. We have already seen acreage calculations done effectively from CFD. In the difficult areas however (reverse flow, transition, etc.) our calculations are aided by ground of flight data.
- What are the implications for not sustaining physical assets?
- What investments (capability improvements and measurement/test techniques) need to be made? How are investment priorities determined? With RDT&E projects becoming more transactional, who will fund these investments?
- How can these methods be better integrated, with near real-time interaction?

Planned Follow-up:
Virtual Panel

A group of additional subject matter experts have been assembled to serve as 'virtual panelists'. Following this session, the content documentation will be organized to list the context comments and questions/subjects from that session. Each virtual panelist will provide written comments to each question/subject and all material will be combined into a work product.

Work Product and Second Session

The CASE session work product will be a briefing that will be used as an oral presentation to introduce a second panel session at the **AIAA SciTech 2014** (January, National Harbor, MD). This session will be focused on addressing the issues raised here, in terms of best practices, solutions, and great ideas. It is planned to also augment this panel session with virtual panelists. All inputs will be compiled and documented in a conference session paper.

APPENDIX 2

Virtual Panel Logistics

Approach: An initial work product from session 1 was produced and sent to several "virtual" panelists, with guidance to add comments to both the topics and the documented responses. Feedback was received from four individuals.

Panelists:
1. Mr. Steven Bauer, Research Aerodynamicist, NASA/LaRC

2. Dr. Georg Eitelberg, Director, DNW

3. Mr. Dan Marren, Facility Manager, AEDC Tunnel 9 in White Oak

4. Dr. Greg Power, Technical Fellow, Computational Modeling and Simulation, ATA/AEDC

Integration of Feedback:
Comments were added to the work product from the first panel session and shared, in advance, with the session 2 panelists.

APPENDIX 3

Logistics of Panel Session 2

Session: **The Direction and Integration of Experimental Ground Test Capabilities and Computational Methods, Part II**

Subject: Building on the work and findings from CASE, this second session seeks to address issues and project a future state. After a short CASE session summary, an interactive panel session follows that will project the future direction of capability needs (including measurement and data acquisition), people development, financial and technical environments, and capability alignment. What is the future state that stakeholders and decision makers should be using for planning and building?

Venue: Gaylord National Resort and Convention Center, National Harbor, MD

Date: January 15th, 2014

Panelists:
1. Mr. Alex Krynytzky, Aerodynamics/Noise/Propulsion Laboratories, The Boeing Company, Seattle, WA

2. Mr. Shigeya Watanabe, Chief Engineer, Japan Aerospace Exploration Agency

3. Mr. Tom Wayman, Core Engineering Group Head in Applied Aerodynamics at Gulfstream Aerospace Corporation in Savannah, GA

4. Dr. Rubén Del Rosario, Manager of the Fixed Wing Project in NASA's Fundamental Aeronautics Program

5. Dr. Edward Marquart, Engineering Fellow on the staff of the Flight Science Department in the Engineering Directorate at Raytheon Missile Systems, Tucson, AZ

6. Dr. Greg Power, Technical Fellow, Computational Modeling and Simulation, ATA/AEDC

Facilitators (and Session Co-Chairs): Dr. Steven Dunn, Jacobs and Mr. Terry Trepal, Institute for Defense Analysis

Topics Posed:

Topic 1: Aligning Experimental Capabilities with Computational Development
- What are the top three critical risks?
    - Premature closure of important experimental facilities
    - Lack of effective coordination between ground test (flight test) and CFD
    - Failure to adequately validate and verify computational models
    - Unrealistic expectations with respect to computational capabilities
    - Underestimating the length of time and the cost required for grid generation
    - Underestimating the amount of computing time needed for complex configurations
- Is there a possibility that sufficient computing power will be available in 30 years to accurately simulate turbulent flows and develop advanced turbulence models? Chemically reacting flows? Multi-disciplinary analyses for aerospace vehicle design?
    - Or, can certain categories of aeronautical phenomena (e.g., turbulence modeling, highly separated flows) be confidently reserved for investigation in experimental facilities for the foreseeable future?
- In the next 30 years, how successful will the computational community be in resolving problems associated with grid generation?

- Will useful quantum computing be available in the next 20 years? If so, how much physical testing may be obviated?

Topic 2: What is the strategy (and the associated tactics) for developing people competent in both (experimental and computational) domains?
- Should a certain amount of cross training be part of the academic preparation for students in aerospace engineering, materials engineering, etc.?
- Should aerospace companies and Government organizations involved in research, development, test and evaluation activities related to aerospace vehicles establish:
    - Policies and practices that encourage, if not require, personnel involved in the development of CFD code and personnel involved in experimental testing, as well as those responsible for vehicle design, to be trained, and actually work, in both domains?
    - Establish rotational assignments to ensure that their personnel develop and maintain competence in both domains? (Specialists in CFD are often sent to work with experimental personnel in the development of aerospace vehicles, but experimentalists are not normally dispatched to work with computationalists.

Topic 3: Are there new computational and measurement tools that need to be developed in tandem with new (and existing) ground test capabilities and computational methods so that aerospace vehicle development is enhanced and risk is reduced?
- Mastering the challenges of the future aeronautics, both the CFD as well as the EFD will produce massive amounts of data; Eitelberg suggests possibly a new specialty: the data reductionist
- Bring tools to T&E that offer a deeper knowledge of the physics which in turn informs (or validates) our CFD
- Leverage physics-based design methods for system design. We see labs and S&T use physics based tools but do we successfully help transition these tools to industry or acquisition?
- Bring tools that
    - Align methodologies within tests, between tests, and between experimental and computational
    - Provide rapid feedback and turnaround, especially for evolved configuration changes.

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Acknowledgments

References

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