

Update: Partnership for the Revitalization of National Wind Tunnel Force Measurement Technology Capability

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NASA's Aeronautics Test Program (ATP) chartered a team to examine the issues and risks associated with the lack of funding and focus on force measurement over the past several years, focusing specifically on strain- gage balances. NASA partnered with the U.S. Air Force's Arnold Engineering Development Center (AEDC) to exploit their combined capabilities and take a national level government view of the problem and established the National Force Measurement Technology Capability (NFMTC) project. This paper provides an update on the team's status for revitalizing the government's balance capability with respect to designing, fabricating, calibrating, and using the these critical measurement devices.

Nomenclature

AEDC = Arnold Engineering Development Center
ARC = Ames Research Center
ARMDC = Aeronautics Research Mission Directorate
ATP = Aeronautics Test Program
DoD = Department of Defense
FTE = Full-time equivalent
GRC = Glenn Research Center
LaRC = Langley Research Center
NASA = National Aeronautics and Space Administration
NFMTC = National Force Measurement Technology Capability
POC = Point of contact
R&D = Research and development

I. Introduction

The Aeronautics Test Program (ATP) was created by NASA to preserve the capabilities of the largest, most versatile and comprehensive set of testing facilities in the United States. The portfolio of ATP facilities appears in Fig. 1. The goals of the ATP include increasing the probability of having the right capabilities in place at the right time, operating the necessary facilities in the most effective and efficient manner possible to foster those capabilities through a corporate management philosophy, and ensuring intelligent investment and divestment while sustaining core capabilities. The ATP attempts to achieve these goals by management initiatives such as integrated management of the facility portfolio, internal and external agreements, competitive pricing and rate structure, and user awareness events, as well as through investment activities for operations and maintenance support, test capability sustainment and test technology and facility research.

<u>AMES RESEARCH CENTER</u>	<u>LANGLEY RESEARCH CENTER</u>
<ul style="list-style-type: none"> • 11-ft Transonic Unitary Wind Tunnel • 9x7 Supersonic Wind Tunnel • 12-ft Subsonic Pressure Wind Tunnel 	<ul style="list-style-type: none"> • National Transonic Facility • 0.3-m Transonic Cryogenic Tunnel • 8-ft High Temperature Tunnel • 20-in. Mach 6 CF4 Tunnel • 31-in. Mach 10 Tunnel • 15-in. Mach 6 Tunnel • 20-in. Mach 6 Hypersonic Tunnel • 20-in. Supersonic Wind Tunnel • 22-in. Mach 20 Hypersonic Tunnel • 14x22 Subsonic Wind Tunnel • Transonic Dynamics Tunnel • 4-ft Supersonic Unitary Wind Tunnel • 20-ft Vertical Spin Tunnel • Low-Turbulence Pressure Tunnel • Jet Exit Test Facility • 30x60 Full-Scale Tunnel
<u>DRYDEN FLIGHT RESEARCH CENTER</u>	
<ul style="list-style-type: none"> • Western Aeronautical Test Range • Support and Test-Bed Aircraft • Flight Loads Laboratory • Flight Simulators 	
<u>GLENN RESEARCH CENTER</u>	
<ul style="list-style-type: none"> • Icing Research Tunnel • 10x10 Supersonic Unitary Wind Tunnel • 8x6 Transonic Wind Tunnel • 9x15 Low Speed Wind Tunnel • Propulsion Systems Lab 3 and 4 • ECRL-2B • Aero-Acoustic Propulsion Laboratory • Hypersonic Test Facility 	

Figure 1. Aeronautics test program facility portfolio.

With that backdrop, the ATP evaluated core competencies within its portfolio of facilities and became increasingly concerned about the state of force measurement at NASA. Force measurement is a technology that is critical for wind tunnel testing and is a highly specialized, experience-based niche market for a few precision machine shops around the country. At NASA, lack of funding and decentralization had eroded the capability to not only produce, calibrate and repair balances, but even to use them in novel test arrangements. The number of usable balances in the inventory was on the decline along with safeguards against catastrophic failure. The aeronautics industry retained some in-house capability, but it seemed to be deteriorating as well.

Thus, the ATP has identified force measurement as one of the fundamental capabilities to achieve its charter. Strain-gage balance technology is a *key aeronautical capability* addressed by the National Aeronautics R&D Policy, “*We will dedicate ourselves to the mastery and intellectual stewardship of the core competencies of Aeronautics,*” and “*key aeronautical capabilities.*” Capability in this technology is not one that NASA can readily purchase - the instruments are complex and require an extensive experience-based competency.

II. Establishment of the NFMTTC

The National Force Measurement Technology Capability (NFMTTC) project office was organized as shown in Fig. 2 (and introduced in reference 1). Project implementation includes representation from NASA Ames Research Center, NASA Glenn Research Center, NASA Langley Research Center, and the U.S. Air Force’s Arnold Engineering and Development Center. Problem solving will be accomplished through the Project Team with help from the Advisory Team as needed. The Advisory Team, comprised of the Center ATP Program Manager, the ATP Points-of-Contact (POC), and key representatives from NASA and Department of Defense (DoD) Programs, will provide input to the NFMTTC Office on its planning and implementation plans from a customer perspective. This input is advisory-only and not mandated to the office. Technical representatives from each of the centers participate in all aspects of project planning and provide onsite technical support at each of the locations.

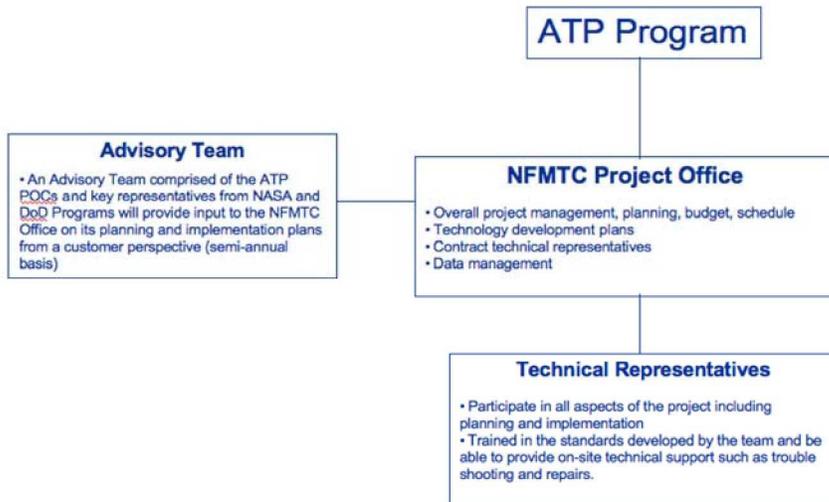


Figure 2. Force measurement project organization.

While concentrated on balances with a capabilities-based activity, the project touches a wide swath of topics and issues to meet its goals. These include:

- Force measurement design, strain-gaging, calibration, and fabrication
- Materials, sensors, stress analyses, fracture mechanics, and fatigue analyses
- Balances, calibration systems, inspection techniques
- Statistical engineering (Design of Experiments (DOE), Response Surface Methodology RSM), uncertainty analyses, statistical quality control
- Standards and training documents
- Trained personnel in force measurement technology

III. Status of the NFMTc Objectives

The project objectives and respective approaches are described below along with a status for each.

Objective 1: Re-capitalize NASA’s strain-gage balance inventory.

Approach: Develop a national database, balance readiness evaluation criteria, and a prioritized list of balances to add/modify in order to increase readiness for use inventory

Status: The National Database has been re-established and populated with the current inventory. A balance readiness criteria has been established and the process of evaluating the balances initiated. A snapshot of the database is shown in figure 3. In addition, several new balances have been acquired/developed to begin the re-capitalization process. Figure 4 shows one of two Triumph Aerospace designed and produced 2.0-inch diameter Hi-Cap (hi-capacity) balances that fulfill a need in that test envelope. Figure 5 displays a semi-span balance, NTF-117S, that was completed by the NMFTc project utilizing Modern Machine and Tool (MM&T) Company. The NTF-117S balance enables an increased load capability for the NASA LaRC National Transonic Facility (reference 2 describes the NTF-117S balance development and initial use in more deatail). In addition, this balance will enable dual pressure lines to pass through the center to enable powered testing. Figure 6 is a picture of the newest balance development that was designed by NFMTc personnel and is currently being machined at MM&T. This balance will fill a semi-span testing load envelope primarily for Ames Research Center.

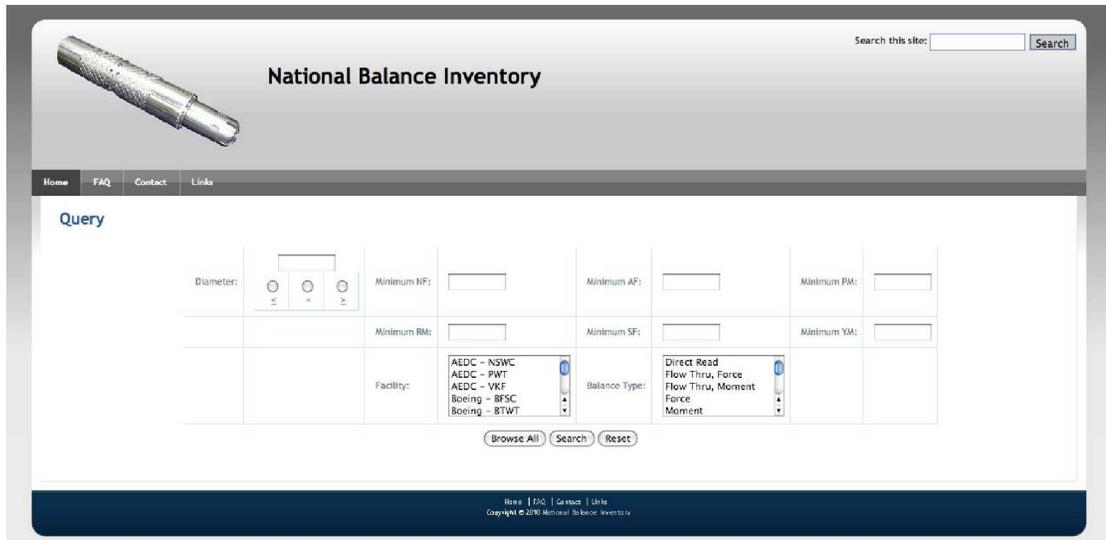


Figure 3. National Balance Inventory Website: Natbalinv.com



Figure 4. MC-60H-2.00E Balance



Figure 5. NTF-117S Balance

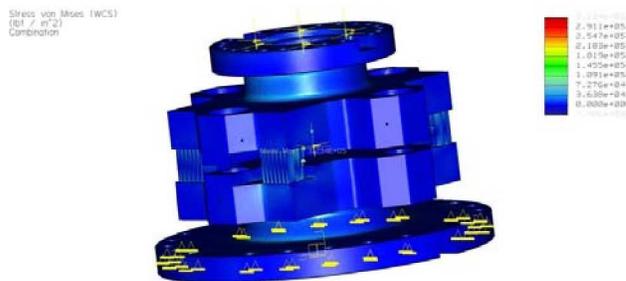


Figure 6. New Semi-Span Balance for NASA Ames (finite element analysis and rough machining photo)

Objective 2: Develop a best practices guide for NASA strain-gage balance technology.

Approach: Assemble best practices in all areas of balance development from each Center, AIAA, industry, and academia.

Status: This objective is being addressed in two areas. The first step was to establish best practices in calibration and balance design/stress analysis. In balance calibration, fundamental standards are being reviewed such as weight and data system calibration requirements and practices. In the design area, a team is reviewing the finite element analysis techniques used to certify balance safety factors. The second step was to initiate the AIAA Ground Testing Technical Committee (GTTC) Internal Balance Technology Working Group (IBTWG) II. This Group will bring together experts and users from around the world to develop a new Recommended Practices Guide. The Group held its initial meeting in January 2010. Listed below is a quick summary of the IBTWG II charter.

1. Review the recommended math model or calibration matrix (6x96) and update it to a smaller or larger matrix based on the group's investigations. Provide guidance/ formulas, on selecting the appropriate subset matrix for a particular balance and calibration load schedule.
2. Investigate uncertainty estimate calculations to provide better estimates of the balance calibration uncertainty. This will include items such as separating the balance uncertainty from the calibration system.
3. Provide recommendations for thermal effects on balance performance. This will include physical and numerical compensation techniques for zeros and calibration coefficients. The initial focus will be on steady state temperatures and followed with temperature gradient recommendations.
4. Investigate and provide recommendations on how to include pressure effects (due to internal balance flow) on the balance performance (calibration).
5. Develop metrics for evaluating a balance's condition to help determine if it needs to be calibrated and the level of calibration needed.
6. Review the current axis system and determine if it is appropriate to shift to an international standard.
7. Provide recommendations on wind tunnel check loads that will assist in transferring the calibration uncertainty to the facility where the balance is used.

Objective 3: Improve balance calibration capability.

Approach: Assess current techniques and provide recommended improvements and practices through quantitative analyses.

Status: A balance calibration study was undertaken to evaluate the current balance calibration systems in use today across the US. Calibrations have been performed on two representative balances and three calibration systems to date. The data is currently being evaluated along with developing a strategy to perform additional calibration experiments in the future. The reason to develop the additional experiments is to provide additional information that will enable a better development of the calibration system uncertainties. Additional calibration systems will also be included in the follow-on experiments. Figure 7 lists the balances and systems used for the calibration study that have been completed.

The NFMTC is supporting the recommissioning of the Triumph semi-span balance calibration system or Large Load Rig (LLR). This system will provide a source for performing semi-span balance calibrations in an efficient manner. Figure 8 is a picture of the LLR at Triumph during the assessment phase of the recommissioning.

BalFit, a software package developed at NASA ARC is being supported by the NFMTC to enable improved balance data analyses and common report generation. This is a very valuable tool that will be made available to the Nation once completed.

Balances	Calibration Systems		
	LaRC Manual	Triumph ABCS	LaRC SVS
Task MK 29	X	X	X
NTF-113C	X	X	

Figure 7. Balance Calibration Study Matrix



Figure 8. Semi-Span Calibration System (Triumph Large Load Rig)

Objective 4: Establish and maintain staffing to sustain capability.

Approach: Establish technical staff needed for the organization and develop training plans for each technical discipline.

Status: The project has established the capabilities needed to meet objectives developed in the project plan and updated in this report. Personnel have been working these areas since the project start and continue to be active and funded appropriately. The appropriate level will be evaluated each year and adjusted based on the facility needs. In addition, NFMTC personnel are teaming to develop balance training that will encompass best practices across the facilities. The first step has been to assemble current training slides from AEDC, LaRC and ARC. These will then be combined within the next few months into an integrated introduction to balance technology aimed at facility users.

Objective 5: Reduce contract task “turn-on” time.

Approach: Coordinate contract administration and streamline process to access all major balance vendors.

Status: The NFMTC project personnel have been actively engaged in utilizing the NASA contract mechanisms to minimize turn-on time. Two of the current contract vehicles include the Force Measurement Support Service Contract (FMSS), and the Reliance Consolidated Models Contract (RECOM). Figure 8 is a picture of one of two load cells that were strain-gaged for NASA’s Dryden Flight Research Center (DFRC) that are assembled into a force balance used flight test experimentation. The FMSS contract based at LaRC was used without burdening the DFRC personnel with a lengthy procurement process since the FMSS is a task order contract already in-place. The task was initiated in less than one week after initial requirements were provided. Figure 9 is a picture of one of the load carts developed under the RECOM contract for NASA Glenn Research Center (GRC). Again, this enabled personnel at GRC to utilize this existing contract mechanism. Another example of the efficiency of this contracting philosophy was the repair and check calibration of a Navy owned balance that was used by Boeing in a test at NASA Ames Research Center (ARC). The balance was originally developed by MM&T. Therefore, the preferred option was to have MM&T perform the minor repairs and calibration. ARC personnel contacted LaRC and the task was in-place in less than a week.

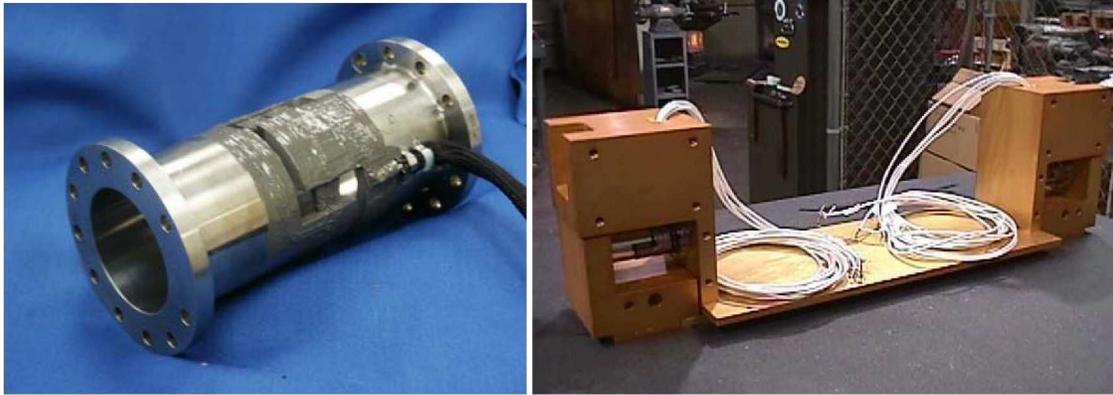


Figure 10. DFRC Load Cell and Assembled Force Balance



Figure 11. GRC Load Carts

Objective 6: Increase research and development investment.

Approach: Develop coordinated research and development plan.

Status: This objective is just receiving attention from the NFMTC personnel. The only active project is a Small Business Innovative Research (SBIR) project that is investigating fiber-optic based balance technology. A comprehensive plan will be developed prior to the end of the current fiscal year (September 30, 2010).

Objective 7: Collaborate with AEDC on force measurement activities.

Approach: Develop a Memorandum of Agreement (MOA) to coordinate all activities within this implementation plan with AEDC through either concurrence or shared responsibilities.

Status: The NFMTC is working two initiatives across NASA and AEDC. Figure 11 is a graphic of a weight basket concept for NASA ARC that is being openly shared with the designers of the AEDC weight basket.

A new need that is just getting underway is the improvement of high-temperature balances for hypersonic facility testing. This will investigate new balances and sensors to decrease size and improve performance at elevated temperatures.

New ARC Concept

(preliminary)



MM&T/NASA LaRC



ARC

Figure 12. Weight Basket Development

Objective 8: Collaborate with industry and academia on force measurement activities.

Approach: Develop activities to collaborate with industry and academia.

Status: The main source of collaboration is the AIAA GTTC IBTWG II. However, NASA currently has co-op students and contracts with universities and industry working active tasks on balance calibration analyses. Activities to engage students and industry partners will be a continual pursuit.

Objective 9: Be recognized as the force measurement consultants for NASA.

Approach: Develop informational brochure and contact lists within the NASA force measurement user community.

Status: Organizational briefings have been organized and conducted at NASA LaRC. These forums will be expanded to other Centers. Also, an informational brochure has been initiated and will be available for the AIAA conference in June 2010.

Objective 10: Establish a business management strategy

Approach: Develop a business management strategy to sustain force measurement capabilities.

Status: The business management strategy has four main components.

1. Revenue generating activities (services provided)
 - a. Expert technical services
 - b. Task monitoring/consulting tax (existing contracts)
 - c. Compete for proposals within NASA and other Agencies
2. Non-revenue generating activities (ATP core functions)
 - a. Calibration practices/software/temperature compensation/data reduction methodology
 - b. Clearinghouse for ATP test technology proposals
 - c. Inventory update/maintenance
3. Marketing
 - a. Successful projects
 - b. Conferences/papers

- c. Brochure materials/website
 - d. Facility and relevant group presentations
 - e. Balance Symposium
 - f. Word of mouth
4. New Products/Technologies/Capabilities

Two examples of this strategy are shown in figures 13. Both were NASA program customers in need of balances for upcoming tunnel entries. The NFMTC was able to provide expert consultation to enable modifications to existing balances to improve/enhance the data quality through design modifications, strain-gaging and calibration.

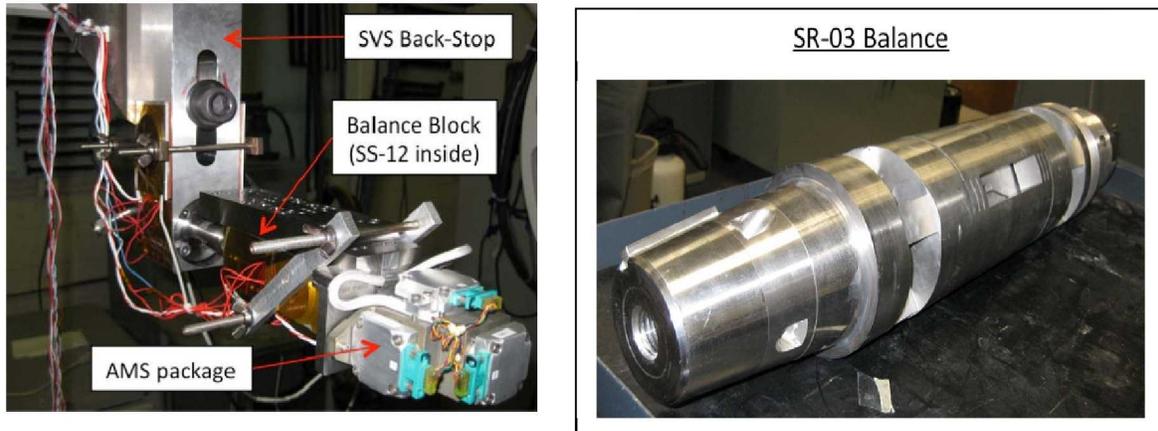


Figure 13. SS-12 Pressure and Temperature Calibration/SR-03 5 inch Dia. Balance Modification

IV. Summary

The ATP determined that balance technology was a critical element to success. Therefore, it initiated a study to determine the necessary strategy for ensuring this critical capability was maintained and improved to meet the ATP mission. As a result, the NFMTC project was established to meet ATP's needs. The NFMTC objectives as established during the planning activity have been updated in this report.

Acknowledgments

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- ² Lynn, K. Chris, "Development of the NTF-117S Semi-Span Balance," Presented at the Seventh International Symposium on Strain-Gauge Balances, May 10-13, 2010.