**FAC 3903 AERODYNAMIC WIND TUNNEL**

| | |
|---|---|
| FY22 SUC: | $1,131,298.82 / EA |
| Source: | Inflated from previous FY using ENR labor and material cost indices to measure actual inflation. |
| Original Source: | Operations & Maintenance Cost Study for NASA Facilities; Final Report for Wind Tunnels. August 13, 2015 |

FY17 SUC Calculation as Follows:

| | | |
|---|---|---|
| Average Sustainment Cost for 23 NASA Wind Tunnels, August 2015 | $907,314.65 | EA |
| ENR Inflation August 2015 to October, 2016 | 1.0257 | |
| FY17 SUC | $930,632.64 | EA |

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# Operations & Maintenance Cost Study for NASA Facilities

# Final Report for Wind Tunnels

**August 13, 2015**

Submitted to:

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# Operations & Maintenance Cost Study for NASA Facilities:
## Final Report for Wind Tunnels

## Overview

National Aeronautics and Space Administration (NASA) requires a credible method for estimating the operations and maintenance (O&M) requirements of its facilities.[1] The failure to anticipate future costs can lead to under-funding and diminished service life.

NASA has over 1,100 buildings totaling 18.4 million GSFT distributed at 33 sites globally in the selected inventory for this project. It is not cost effective to inspect all facilities, yet NASA needs detailed sustainment and operations estimates to support its budget planning. This project developed cost models for a sample of NASA assets with inventory details collected through site surveys. Estimates were extrapolated by facility type and size and adjusted for location to generate requirements for the selected NASA inventory.

The project employed the MARS Facility Cost Forecast System to provide cost information. Now in its eighth version, MARS is a facility cost modeling tool developed by CBRE | Whitestone and used by many federal and commercial agencies.

Completed in March 2013, Phases 1 and 2 of this project estimated O&M costs for four facility types: Administration Buildings, Propulsion Buildings, Communications Buildings, and Space Science (R&D and Test) Buildings. Eight sample buildings were inspected at Goddard and Marshall Space Flight Centers. CBRE | Whitestone submitted formal reports for each facility type.

Phase 3 inspected a sample of two Wind Tunnel facilities at Glenn Research Center (GRC) in Cleveland, Ohio and generated detailed models in MARS. Site inspections were conducted by Jacobs Facilities, a long-time CBRE | Whitestone partner experienced in inspecting federal facilities and creating MARS component inventories. A team consisting of an architect, and electrical and mechanical engineers carried out the facility inspections.

O&M estimates from the sample were extrapolated to the remaining Wind Tunnels in the NASA inventory. The unique function of Wind Tunnels makes common extrapolation variables (per square foot or replacement value) ineffective. Key cost drivers identified by NASA and CBRE | Whitestone dictated how estimates for the sample assets were applied to the total inventory.

This report describes the project methodology and presents final estimates for the Wind Tunnels in the NASA inventory.

[1] Operations include custodial (cleaning, pest control, and trash collection), utilities (energy, water, and sewer), grounds (landscape care, mowing, and snow removal), security, telecommunications, and management. Maintenance (also known as sustainment) includes preventative maintenance, minor repair, unscheduled maintenance, and renewal and replacement.

## Project Methodology

### Parametric Estimates for Buildings

The project methodology entailed estimating O&M requirements for the selected NASA inventory based on the inspection and modeling of a sample of facilities. The project included five key steps:

1. Validate the existing NASA inventory and develop a sample
2. Perform on-site inspections of the sample buildings
3. Develop and calibrate MARS models
4. Develop a mapping and extrapolation methodology and variables for the unique function of Wind Tunnels
5. Generate estimates of sustainment and operations costs for the sample and extrapolate to the project inventory

### Study Sample

NASA has over 1,100 buildings at 33 sites globally in the selected inventory. Complete inspection of each site to estimate O&M requirements is impractical and costly. This project generated sustainment and operations estimates for a sample of buildings and extrapolated the costs to a selected NASA inventory.

NASA selected 23 Wind Tunnel facilities distributed at four sites for this project. The project sample included the inspection of one small supersonic and one large subsonic Wind Tunnel. Staff at NASA HQ, the Aeronautics Test Program, and CBRE | Whitestone selected two Wind Tunnels at the GRC to minimize travel costs for the inspection. Component-level cost models were developed for the two tunnels using CBRE | Whitestone's MARS. The project inventory excluded other Classification types in the NASA inventory, such as Warehouses. Estimates for Administration, Propulsion, Communications, and Space Science (R&D and Test) Buildings were generated in Phases 1 and 2 of the project.

Table 1 shows the building detail for the inspected Wind Tunnels.

**Table 1. Wind Tunnels Inspection Sample**

| Site | Classification | Property No. | Property Name | Year Built | Size[A] | CRV[B] |
|---|---|---|---|---|---|---|
| Glenn Research Center | Wind Tunnels | 39/53/54/57/61 | 9'x15' Low Speed / 8'x6' Supersonic Wind Tunnel | 1949 | 119,514 | $106,691,109 |
| | Wind Tunnels | 37 | 1'x1' Supersonic Wind Tunnel | 1942 | 7,479 | $6,608,331 |
| **Total** | | | | | **126,993** | **$113,299,440** |

[A] Size is the approximate GSFT associated with the wind tunnel from site inspections. GSFT of entire property may exceed inspection sample.
[B] CRV is the Current Replacement Value of the entire property and may exceed the value of the inspected area.

The inspected sample was mapped to the remaining inventory. There are a number of variables that drive O&M costs. In Phase 1 and 2 of the project, building Classification type and size were the key inputs used to determine appropriate mapping of sample facilities to the total inventory. The unique systems and function of the Wind Tunnels prevent O&M costs from closely aligning with facility square footage. NASA and CBRE | Whitestone defined several variables and associated factors used to map the sample models and extrapolate total O&M costs to the remainder of the inventory. The Wind Tunnel mapping and extrapolation is described in detail in a later section of this report.

The 23 Wind Tunnels selected for this project represent 1.2 million GSFT with a $2.9 billion CRV. Table 2 shows the Wind Tunnels inventory by site.

**Table 2. NASA Wind Tunnels by Site**

| Site | Property No. | Property Name | Size[A] | CRV[B] |
|---|---|---|---|---|
| AMES Research Center | N206/N206A | 12' Pressure Tunnel | 36,364 | $253,246,932 |
| AMES Research Center | N215 | 7' X 10' Subsonic Wind Tunnel #1 | 28,763 | $36,488,779 |
| AMES Research Center | N221/N221B | National Full Scale Aerodynamics Complex (NFAC) 40' X 80' & 80' X 120' | 171,129 | $529,305,708 |
| AMES Research Center | N227A/N227B/N227C | 11' X 11', 9' X 7', & 8' X 7' Unitary Plan Transonic Wind Tunnel | 53,580 | $322,857,273 |
| Glenn Research Center | 11/170 | Icing Research Tunnel | 32,501 | $60,139,291 |
| Glenn Research Center | 37 | 1' X 1' Supersonic Wind Tunnel | 7,479 | $6,608,331 |
| Glenn Research Center | 39/53/54/57/61 | 9' X 15' Low Speed Wind Tunnel/8' X 6' Supersonic Wind Tunnel | 119,514 | $106,691,109 |
| Glenn Research Center | 85/87/88/90/113/114 | 10' X 10' Abe Silverstein Wind Tunnel | 170,941 | $297,274,694 |
| Langley Research Center | 1212C | 14' X 22' Subsonic Wind Tunnel | 51,354 | $90,413,562 |
| Langley Research Center | 1236 | National Transonic Facility (NTF) | 79,745 | $393,554,794 |
| Langley Research Center | 1242 | 0.3 Meter Cryogenic Tunnel | 9,276 | $13,304,480 |
| Langley Research Center | 1247D | 20" Mach 6 Tunnel | 100,360 | $141,019,520 |
| Langley Research Center | 1251 | Unitary Plan Wind Tunnel Test Section 1 & 2 | 134,535 | $308,493,730 |
| Langley Research Center | 1251A | 15" Mach 6 High Temperature Tunnel (Hyper. Flow App.) | 24,312 | $3,161,438 |
| Langley Research Center | 1251A | 31" Mach 10 Tunnel | 24,312 | $3,161,438 |
| Langley Research Center | 1265 | 8' High Temperature Tunnel | 25,517 | $124,241,924 |
| Langley Research Center | 1275 | 20" Mach 6 CF4 Tunnel | 17,428 | $27,586,220 |
| Langley Research Center | 644 | 12' Low Speed Tunnel | 3,767 | $6,624,391 |
| Langley Research Center | 645 | 20' Vertical Spin Tunnel | 14,461 | $7,385,933 |
| Langley Research Center | 648 | Transonic Dynamics Tunnel (TDT) | 41,771 | $134,476,694 |
| Marshall Space Flight Center | 4732 | 14" Trisonic Wind Tunnel | 26,773 | $15,864,288 |
| Marshall Space Flight Center | 4775 | High Reynolds Number Wind Tunnel | 3,521 | $838,104 |
| Plum Brook Station | 3411 | Hypersonic Test Facility | 6,082 | $40,988,331 |
| **Total** | | | **1,183,485** | **$2,923,726,964** |

[A] Size is the approximate GSFT associated with the wind tunnel from site inspections. GSFT of entire property may exceed inspection sample.
[B] CRV is the Current Replacement Value of the entire property and may exceed the value of the inspected area.

Detailed cost models were developed for the two Wind Tunnels using CBRE | Whitestone's MARS Facility Cost Forecast System.

## Description of the MARS Model

CBRE | Whitestone used MARS to estimate preventative maintenance, unscheduled maintenance, repair, and renewal/replacement costs for this project. MARS is an asset management system that estimates both deferred maintenance and future requirements on the basis of asset components and their scheduled maintenance and repair. It also estimates costs for ten operations types in the typical commercial chart of accounts. MARS was originally developed in 1996, and is currently in its eighth version. It is used by many government agencies and commercial concerns.

| | |
|---|---|
| Sustainment | Preventive Maintenance & Minor Repair<br>Unscheduled Maintenance<br>Renewal & Replacement |
| Operations | Custodial<br>Energy<br>Grounds<br>Management<br>Pest Control<br>Refuse<br>Road Clearance<br>Security<br>Telecom<br>Water/Sewer |

Note that the definition of future M&R requirements is the same as the "sustainment" requirements used for programming by DoD and an approach endorsed in a National Research Council (NRC) study of Department of Energy facility practices.[2] Among other agencies, the MARS Facility Cost Forecast System has been used to forecast budgets for the IRS, FAA, USDA, and CDC. It was recently used to benchmark costs for the Department of State Overseas Embassies. MARS is also the basis for the DoD Sustainment Model and a study for NNSA validating total life-cycle facility costs at eight nuclear weapons production and research sites.[3] The model is used continuously to simulate alternative facility costs for the U.S. nuclear complex.

The MARS process begins with a component inventory of a building or structure. Derived from building plans, equipment inventory data, and on-site inspections, these components are organized into UNIFORMAT category level three elements and are identified specifically in terms of product characteristics, quantity, and output level; e.g. "Single-Ply Modified

[2] National Research Council, *Intelligent Sustainment and Renewal of Department of Energy Facilities and Infrastructure, 2004*. P. 44.

[3] Jacobs Facilities and Whitestone Research, *Implementation of the Department of Defense Sustainment Model, Final Report*, May 2002.

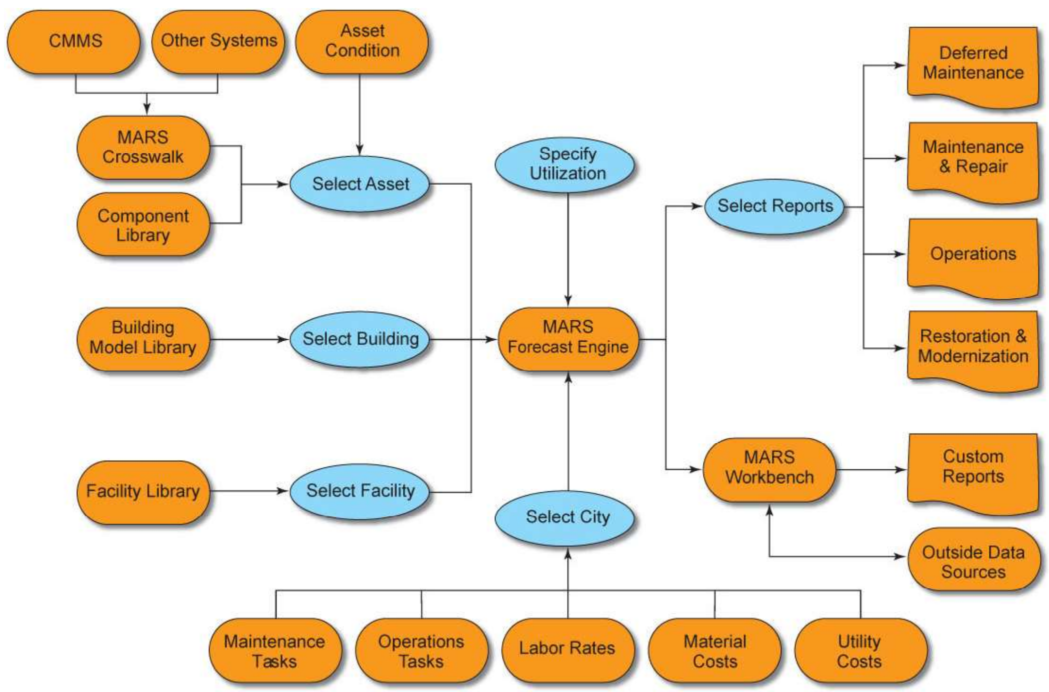
Bituminous/Thermoplastic Roof," "Condenser, Air-Cooled, 60 Ton," or "Pipe & Fittings, ¾" Copper."

Once the component inventory is completed, the MARS system relates maintenance tasks from a pre-defined task library to each selected component. New components and related tasks are defined as necessary. The frequency of each task determines the forecast of future required maintenance. MARS estimates four types of maintenance: preventative maintenance, unscheduled maintenance (service calls), repair, and renewal/replacement tasks. Tasks and their labor and material requirements are pre-defined by CBRE | Whitestone, but are also editable.

Other calibration steps include modifying default values for contract and in-house labor rates, specifying site-typical mark-up for contract expenditures, and identifying the utilization characteristics for each asset.

The sources for local wage rates and benefits are primarily the U.S. Department of Labor and Davis-Bacon Act labor agreements, and private sector employers. Both union and non-union wages are considered in determining prevailing rates by locality. State and local wage surveys are also used when available.

**MARS Facility Cost Forecast System**




MARS is also used to estimate operations costs other than maintenance and repair. These are based on the Facilities Operation Model developed jointly by the Department of Defense (DOD) and CBRE | Whitestone. This model provides costs for ten services, including those mentioned in the Federal Real Property Council (FRPC) guidance—utilities, cleaning and janitorial, and roads and grounds.[4] Each operation type for an asset can be calibrated for a level of service (low, medium, high) to reflect the level of demand or frequency at which certain operations task are performed.

The CBRE | Whitestone operations cost models provides estimates for the following services:

> **Custodial.** The custodial function represents the expense of cleaning offices, work areas, restrooms and common areas. Costs include local wage rates and benefits, task productivity, mark-ups for equipment, materials, supervision, and assumptions concerning the level of service. Trash removal costs are not included. Custodial service levels are defined by altering the combination and frequency of common tasks.
>
> **Energy.** Energy includes all expenses related to the purchase, generation, distribution, and conservation of energy and source fuels necessary to operate an asset. The main energy sources considered are electricity and natural gas. Not included are utilities maintenance and supervision, and utility tax rates. Service levels vary according to estimated commodity demand by asset use type.
>
> **Grounds.** The grounds function includes any expense related to the maintenance of exterior landscaping. It does not include sweeping or the maintenance of signage, parking lots and roadways. Costs are estimated using local wage rates and benefits, task productivity, mark-ups for equipment, materials and supervision, and assumptions concerning the level of service. Service levels are defined by altering the combination and frequency of common tasks.
>
> **Management.** The real property management function describes all costs associated with facility management, including: public works, contracts, material procurement, facility data, furnishings, real estate, and engineering services. Costs are expressed as a fixed percentage of Plant Replacement Value. Service levels are based on the distribution of costs found in institutional and commercial settings. For this project, the level of service for all NASA buildings was set to low to reflect economies of scale in a campus environment.
>
> **Pest Control.** Pest control expenses cover indoor and outdoor pest control programs, separate from the grounds function. Costs are based on the frequency of common tasks for rodent and insect abatement and inspections. Costs include prevailing labor and material rates. Service levels are defined by altering the combination and frequency of common tasks.
>
> **Refuse.** Refuse costs include all expenses related to trash collection and disposal, pick-up services, fees, recycling operations and administration, composting, etc. Costs exclude handling and disposal of HAZMAT materials. Service levels vary according to estimated demand by asset use type.
>
> **Road Clearance.** The road clearance function includes all expenses related to sweeping paved areas including sidewalks, walkways, and parking lots. Costs include prevailing labor and material rates, and climatic variables. Service levels are defined by altering the combination and frequency of common tasks.

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[4] Federal Real Property Council. *Guidance for Real Property Inventory Reporting.* Washington, D.C. August, 2012.

**Security.** Security expenses relate to the physical security of assets and occupants, and include personnel, operating and monitoring security equipment. Costs include relevant prevailing labor and material rates. Service levels are defined by altering the combination and frequency of common tasks and services.

**Telecommunications.** Telecommunication expenses cover the purchase of all the services ordinarily associated with commercial activities, such as voice and data equipment and service subscription. The level of telecommunications is defined by the combination of services selected.

**Water and Sewer.** Water and Sewer expenses include all costs related to providing the asset with potable water, irrigation water, and sewage service. Estimates include local commodity costs. Service levels vary according to estimated commodity demand by asset use type.

## Data Collection and Calibration

### MARS Model Development

The technical work for this task involved the definition of the component inventory for the two sample Wind Tunnels. Glenn Research Center staff supplied existing equipment inventories and construction design documents before the inspection. Jacobs Facilities inspected the Wind Tunnels and created draft models in MARS. Due to the unique systems in the Wind Tunnels, Jacobs created 162 unique components in MARS. In total, 867 components were used in the models of the two facilities.

Jacobs submitted the MARS database to CBRE | Whitestone for a detailed component-by-component review. Three areas of focus included:

**1)** Check for completeness. Review the wall finishes (exterior and interior), roofing, plumbing, HVAC, fire protection, and electrical data to ensure the building model contains the appropriate components in each category.

**2)** Check for consistency. Review the building gross square feet for accuracy. Ensure the square footage of structural components (exterior walls, roofing system, interior finishes) are reasonable compared to building GSFT. Verify the capacity of the following is consistent with the building type and size:

- Heating, cooling, and air distribution
- Electrical service, distribution, and lighting
- Plumbing fixtures and water distribution
- Fire protection

**3)** Forecast review. Run the following building-level MARS reports and look for extraordinary costs (high or low) illustrating an error in the building model:

- Average M&R Costs
- Most Costly M&R Tasks

- Deferred Maintenance Detail
- Operation Cost Summary

The sample Wind Tunnel component lists and draft estimates were also provided to NASA staff for review. Any changes were incorporated into this report.

Attachment B and C provide detailed MARS component lists for the two inspected Wind Tunnels at GRC.

CBRE | Whitestone also collected information to calibrate the models for local site values.

**Local Calibration of MARS**

While the MARS system has pre-defined building models, labor and material costs, utility rates, and an extensive component library, all of these values can be changed or supplemented to reflect the actual site practices.

Calibration data was gathered to adjust MARS factors for maintenance & repair and operations costs of the Wind Tunnels. Data was gathered at both the site and the building level. Site-level information, such as labor and utility rates, was directly used to estimate O&M costs for the Wind Tunnels at GRC. Building-level calibration data was applied to the sample models and then extrapolated to the remaining NASA inventory.

The following data was collected to calibrate the building models:

Maintenance and Repair. A default assumption in MARS assigns in-house labor to preventative maintenance, minor repair, and unscheduled maintenance, while contract labor performs major repair and replacement tasks. NASA staff indicated all maintenance was performed by contract laborers. CBRE | Whitestone adjusted the MARS database accordingly.

NASA personnel specified laborers must be paid prevailing wages for the area. We used the default MARS wage rates for this study, and included a 30 percent mark-up for contract overhead.

Table 3 shows the source of the maintenance and repair factors for each site.

**Table 3. Data Sources by Site, Maintenance & Repair**

| Site | In-house Shop Rates | In-house Markup Rates | Contract Labor Rates | Contract Overhead Rates | Utilization |
|---|---|---|---|---|---|
| Glenn Research Center | N/A | N/A | WST | WST | Site |
| WST=Whitestone, Site = Respective NASA Site | | | | | |

MARS estimates also can be adjusted to reflect utilization factors that impact M&R. For example, many NASA facilities have special safety requirements which increase costs relative to conventional commercial practice. Other special requirements include high or low hours of operation and security. Glenn Research Center defined utilization factors for the two sample Wind Tunnels.

Table 4 displays the average utilization multipliers for the sample Wind Tunnels used to adjust for these requirements.

**Table 4. Average Utilization Adjustment by Site[A]**

| Site | Hours of Operation[B] | Security[C] | Safety & Permitting[D] | Sum[E] |
|---|---|---|---|---|
| Goddard Space Flight Center | 1.00 | 1.01 | 1.07 | 1.08 |

[A] Calculated from individual asset multipliers assigned by the sites.
[B] Hours of Operation rates building use on a weekly basis and is defined as follows: 0.80 = 40 hours, 1.00 = 41 to 80 hours, 1.37 = 80+ hours.
[C] Security is defined as follows: 1.00 = free access, 1.01 = contractor training & daily check-in, 1.15 = full contractor accompanyment.
[D] Safety & Permitting is defined as follows: 1.00 = typical commercial & service activity, 1.07 = non-specific laboratory, 1.75 = radiological or life science research, 3.00 = nuclear facility.
[E] In combination the multipliers are additive such that the total multiplier = $1 + \sum(\beta - 1)$ where $\beta$ = the multiplier value.

Operations. MARS also estimates operations costs for ten services including: custodial, energy, grounds, management, pest control, refuse, road clearance, security, telecommunications, and water & sewer. Key drivers of operations estimates include utility rates, labor rates, and mark-ups, which were collected from GRC staff.

In addition, MARS is populated with default levels of service by operation and building type. The building types in MARS are typical to the commercial environment and do not include Wind Tunnels. CBRE | Whitestone worked with NASA staff to develop unique level of service ratings for the Wind Tunnel facilities. The ratings (low, medium, high, or none) reflect the level of utility demand or frequency of operations tasks in these specialized facilities. The sample Wind Tunnels at GRC were assigned a level of service by site staff.

The unique systems and function of the Wind Tunnels prevent utility consumption from closely aligning with facility size. Extrapolating energy and water & sewer costs based on square footage from the sample to the inventory would not generate accurate estimates. To avoid this type of extrapolation, NASA supplied utility rates for all four sites with Wind Tunnels in the inventory, and utility demand for each specific Wind Tunnel. In addition to the utilities estimated in MARS, NASA also provided utility rates and demand for several other types, including process cooling water, chilled water, high pressure air, service air, steam, and altitude exhaust. CBRE | Whitestone calculated total utility costs by multiplying the site rate by each Wind Tunnel's average consumption.

Other utility rates, such as refuse, provided in Phase 1 and 2 were significantly lower than the default MARS commercial rates. These discounts are often provided to large federal property holders like NASA. CBRE | Whitestone applied the average discounts for the previously calibrated sites to the remaining sites in the Wind Tunnel inventory.

As with M&R, CBRE | Whitestone used the default MARS wage rates and a 30 percent mark-up for contract overhead.

Table 5 shows the source of the operations calibration data.

**Table 5. Data Sources by Site, Operations**

| Site | Source |
|---|---|
| Level of Service | GRC |
| Custodial Wage | CBRE \| Whitestone |
| Groundskeeper Wage | CBRE \| Whitestone |
| Property Management | GRC |
| Pest Control Wage | CBRE \| Whitestone |
| Refuse Rates | CBRE \| Whitestone |
| Road Clearance Wage | CBRE \| Whitestone |
| Security Rates | CBRE \| Whitestone |
| Telecom Rates | CBRE \| Whitestone |
| Water/Sewer | ARC / GRC / LaRC / MSFC |
| Building Electricity | ARC / GRC / LaRC / MSFC |
| Tunnel Electricity | ARC / GRC / LaRC / MSFC |
| Natural Gas | ARC / GRC / LaRC |
| Steam | ARC / GRC / LaRC / MSFC |
| Process Cooling Water | ARC / GRC / LaRC |
| 6,000 PSIG Air | LaRC |
| 450 PSIG Air | GRC |
| Service Air | GRC |
| Building 64 Altitude Exhaust | GRC |
| Building 114 Altitude Exhaust | GRC |
| IRT Chiller Plant | GRC |

## Inventory Mapping and Extrapolation

There are a number of variables that drive O&M costs. In Phase 1 and 2 of the project, building Classification type and size were the key inputs used to determine appropriate mapping of sample facilities to the total inventory. Per square foot estimates were generated for the sample and extrapolated to the selected inventory by type (Administration, Propulsion, Communications, and Space Science (R&D and Test) Buildings) and size.

The unique systems and function of the Wind Tunnels prevent O&M costs from closely aligning with facility square footage. NASA and CBRE | Whitestone defined several variables and associated factors used to map the sample models and extrapolate total O&M costs to the remainder of the inventory.

Table 6 shows six variables that will be used to estimate the cost requirements of NASA Wind Tunnels.

**Table 6. Inventory Mapping and Extrapolation Variables**

| Variable[A] | Description |
|---|---|
| Flow Velocity Category | Subsonic, Transonic, Supersonic, or Hypersonic. Used to determine mapping and extrapolation factor. |
| Mach Number | Used to determine mapping and extrapolation factor. |
| Operation Type | Continuous flow or blow-down. Used to determine mapping. |
| Closed or Open Tunnel | Closed-loop or open exhaust tunnel. Used to determine mapping. |
| Test Cell Cross Section Area | Used to determine extrapolation factor. |
| Auxiliary Equipment | Auxiliary cooling water, nozzle type, drying, and drive motor equipment. Used to determine extrapolation factor. |

[A] Variables and extrapolation factors were defined by NASA through research, evaluating maintenance schedules, and historical knowledge of the Wind Tunnel facilities and their operating costs.

While all variables were considered in the mapping effort, air speed (flow velocity and mach number) and operation type (continuous flow or blow-down) were the key variables used to map the two inspected Wind Tunnels to the inventory. Continuous flow sub/trans/supersonic Tunnels were mapped to the 9'x15' Low Speed / 8'x6' Supersonic Wind Tunnel. These tunnels operate for an extended period of time and require special equipment, including large drive motors, to continuously supply air down the tunnel. All blow-down tunnels were mapped to the 1’x1’ Supersonic Wind Tunnel. These tunnels blow a single volume of air down the tunnel and do not operate continuously.

After the sample models were mapped to the inventory, the project team identified the key variables that were used to adjust the sample O&M costs to make them more appropriate for the remaining Wind Tunnels. These variables included air speed (flow velocity and mach number), test cell cross section area, and auxiliary equipment requirements (process cooling water, chiller water, drive motors, integral air dryers, compressors, electrolyte system, and flexwall system). Each variable included a factor to increase or decrease costs relative to the sample models. These factors were developed through research with NASA staff and provided by Pete Aitcheson.

The extrapolation factors were used to estimate O&M costs for each Wind Tunnel in the inventory to which they apply. The continuous flow Tunnels mapped to the 9'x15' Low Speed / 8'x6' Supersonic Wind Tunnel share similar features and all of the variables were applicable. However, only the test cell cross section area was used to determine the O&M costs of the Tunnels mapped to the 1’x1’ Supersonic Wind Tunnel.

Table 7 shows the selected Wind Tunnel inventory by site and the sample model mapping assignment and extrapolation factors.

**Table 7. Inventory Mapping and Extrapolation Factors**

| Site | Property No. | Flow Velocity | Mach Number | Test Cell Area | Operation Type | Closed/Open | Sample Model | Extrapolation Factor |
|---|---|---|---|---|---|---|---|---|
| ARC | N206/N206A | Subsonic | 0 to .55 | 11.25' X 11.25' | Continuous | Closed | 9' X 15' | 0.64 |
| ARC | N215 | Subsonic | 0 to .33 | 7' X 10' | Continuous | Closed | 9' X 15' | 0.47 |
| ARC | N221/N221B | Subsonic | 0 to .45, 0 to .15 | 39' X 79', 79' X 118.3' | Continuous | Closed/Open | 9' X 15' | 4.61 |
| ARC | N227A/N227B/N227C | Trans/Supersonic | 0.4 to 1.4, 1.55 to 2.5, 2.45 to 3.5 | 11' X 11', 9' X 7', 8' X 7' | Continuous | Closed | 9' X 15' | 1.00 |
| GRC | 11/170 | Subsonic | 0.0 to .50 | 6' X 9' | Continuous | Closed | 9' X 15' | 0.52 |
| GRC | 37 | Supersonic | 1.6 to 5.0 | 1' X 1' | Continuous | Closed | N/A | 1.00 |
| GRC | 39/53/54/57/61 | Sub/Trans/Supersonic | 0 to .2 & .4 to 2.0 | 9' X 15'/8' X 6' | Continuous | Closed/Open | N/A | 1.00 |
| GRC | 85/87/88/90/113/114 | Supersonic | 2.0 to 3.5 | 10' X 10' | Continuous | Closed/Open | 9' X 15' | 1.99 |
| LaRC | 1212C | Subsonic | 0 to .3 | 14.5' X 21.75' | Continuous | Closed/Open | 9' X 15' | 1.00 |
| LaRC | 1236 | Transonic | .1 to 1.2 | 8.2' X 8.2' | Continuous | Closed | 9' X 15' | 0.48 |
| LaRC | 1242 | Sub/Transonic | 0.1 to .9 | 13" X 13" | Continuous | Closed | 9' X 15' | 0.06 |
| LaRC | 1247D | Hypersonic | 6 | 20" X 20.5" | Blow down | Closed/Open | 1' X 1" | 1.69 |
| LaRC | 1251 | Supersonic | 1.46 to 2.86 & 2.3 to 4.63 | 4' X 4' | Continuous | Closed | 9' X 15' | 0.66 |
| LaRC | 1251A-15" | Hypersonic | 6 | 14.5" Dia. | Blow down | Closed | 1' X 1" | 1.07 |
| LaRC | 1251A-31" | Hypersonic | 10 | 31" X 31" | Blow down | Closed | 1' X 1" | 2.58 |
| LaRC | 1265 | Hypersonic | 3, 4, 5, & 7 | 8' Dia. | Blow down | Open | 1' X 1" | 7.07 |
| LaRC | 1275 | Hypersonic | 6 | 20" Dia. | Blow down | Closed | 1' X 1" | 1.48 |
| LaRC | 644 | Subsonic | 0 to 61 MPH | 12' Octagon | Continuous | Open | 9' X 15' | 0.02 |
| LaRC | 645 | Subsonic | 0 to .08 | 20' Dia. | Continuous | Closed | 9' X 15' | 0.12 |
| LaRC | 648 | Transonic | 0 to 1.12 | 16' X 16' | Continuous | Closed | 9' X 15' | 0.94 |
| MSFC | 4732 | Sub/Trans/Supersonic | .2 to 3.5 | 14" X 14" | Blow down | Closed | 1' X 1" | 1.17 |
| MSFC | 4775 | Supersonic | .3 to 3.5 | 32" Dia. | Blow down | Closed | 1' X 1" | 2.36 |
| PBS | 3411 | Hypersonic | 5, 6, & 7 | 42" Dia. | Blow down | Closed | 1' X 1" | 3.10 |

A detailed summary of the methodology and calculations used to determine the Wind Tunnel utility costs, inventory mapping, and extrapolation factors was provided by Pete Aitcheson, NASA HQ Operations and Maintenance Program Manager. This summary can be found in Attachment A of this report.

## Cost Estimates for Wind Tunnels

### Sustainment Costs

The sustainment estimate for the 9'x15' Low Speed / 8'x6' Supersonic Wind Tunnel (Property No. 39/53/54/57/61) is an average of $1.2 million per year over a 50-year period. The 1’x1’ Supersonic Wind Tunnel (Property No. 37) is $167 thousand over the same period.

The sample estimates were extrapolated to the population. Table 8 shows sustainment costs by site for all Wind Tunnels. Sustainment estimates are expressed as 30, 40, and 50-year averages. While CBRE | Whitestone computes annual requirements, average costs are presented to smooth the annual oscillations. Overall, the sustainment requirements are an average of $20.9 million per year over 50 years. Expressed another way, this amounts to 0.7 percent of the $2.9 billion replacement value.

**Table 8. Average Annual Estimates of Sustainment Requirements by Site, Wind Tunnels**

| | | | | Sustainment[A] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 30-Year Estimates | | | 40-Year Estimates | | | 50-Year Estimates | | |
| Site | Property No. | GSFT[B] | CRV[C] | Avg. Annual Estimate | Per GSFT | Percent CRV | Avg. Annual Estimate | Per GSFT | Percent CRV | Avg. Annual Estimate | Per GSFT | Percent CRV |
| ARC | N206/N206A | 36,364 | $253,246,932 | $980,441 | $26.96 | 0.4% | $1,020,883 | $28.07 | 0.4% | $975,942 | $26.84 | 0.4% |
| ARC | N215 | 28,763 | $36,488,779 | $720,011 | $25.03 | 2.0% | $749,711 | $26.07 | 2.1% | $716,707 | $24.92 | 2.0% |
| ARC | N221/N221B | 171,129 | $529,305,708 | $7,062,237 | $41.27 | 1.3% | $7,353,545 | $42.97 | 1.4% | $7,029,829 | $41.08 | 1.3% |
| ARC | N227A/N227B/N227C | 53,580 | $322,857,273 | $1,531,939 | $28.59 | 0.5% | $1,595,129 | $29.77 | 0.5% | $1,524,909 | $28.46 | 0.5% |
| GRC | 11/170 | 32,501 | $60,139,291 | $627,642 | $19.31 | 1.0% | $653,531 | $20.11 | 1.1% | $624,761 | $19.22 | 1.0% |
| GRC | 37 | 7,479 | $6,608,331 | $169,293 | $22.64 | 2.6% | $164,256 | $21.96 | 2.5% | $167,314 | $22.37 | 2.5% |
| GRC | 39/53/54/57/61 | 119,514 | $106,691,109 | $1,207,003 | $10.10 | 1.1% | $1,256,790 | $10.52 | 1.2% | $1,201,464 | $10.05 | 1.1% |
| GRC | 85/87/88/90/113/114 | 170,941 | $297,274,694 | $2,401,936 | $14.05 | 0.8% | $2,501,013 | $14.63 | 0.8% | $2,390,914 | $13.99 | 0.8% |
| LaRC | 1212C | 51,354 | $90,413,562 | $998,375 | $19.44 | 1.1% | $1,039,557 | $20.24 | 1.1% | $993,794 | $19.35 | 1.1% |
| LaRC | 1236 | 79,745 | $393,554,794 | $479,220 | $6.01 | 0.1% | $498,987 | $6.26 | 0.1% | $477,021 | $5.98 | 0.1% |
| LaRC | 1242 | 9,276 | $13,304,480 | $59,903 | $6.46 | 0.5% | $62,373 | $6.72 | 0.5% | $59,628 | $6.43 | 0.4% |
| LaRC | 1247D | 100,360 | $141,019,520 | $236,653 | $2.36 | 0.2% | $229,611 | $2.29 | 0.2% | $233,886 | $2.33 | 0.2% |
| LaRC | 1251 | 134,535 | $308,493,730 | $658,928 | $4.90 | 0.2% | $686,108 | $5.10 | 0.2% | $655,904 | $4.88 | 0.2% |
| LaRC | 1251A-15" | 24,312 | $3,161,438 | $149,834 | $6.16 | 4.7% | $145,375 | $5.98 | 4.6% | $148,082 | $6.09 | 4.7% |
| LaRC | 1251A-31" | 24,312 | $3,161,438 | $361,281 | $14.86 | 11.4% | $350,531 | $14.42 | 11.1% | $357,057 | $14.69 | 11.3% |
| LaRC | 1265 | 25,517 | $124,241,924 | $990,022 | $38.80 | 0.8% | $960,562 | $37.64 | 0.8% | $978,447 | $38.34 | 0.8% |
| LaRC | 1275 | 17,428 | $27,586,220 | $207,246 | $11.89 | 0.8% | $201,080 | $11.54 | 0.7% | $204,823 | $11.75 | 0.7% |
| LaRC | 644 | 3,767 | $6,624,391 | $19,968 | $5.30 | 0.3% | $20,791 | $5.52 | 0.3% | $19,876 | $5.28 | 0.3% |
| LaRC | 645 | 14,461 | $7,385,933 | $119,805 | $8.28 | 1.6% | $124,747 | $8.63 | 1.7% | $119,255 | $8.25 | 1.6% |
| LaRC | 648 | 41,771 | $134,476,694 | $938,473 | $22.47 | 0.7% | $977,184 | $23.39 | 0.7% | $934,166 | $22.36 | 0.7% |
| MSFC | 4732 | 26,773 | $15,864,288 | $179,683 | $6.71 | 1.1% | $174,337 | $6.51 | 1.1% | $177,583 | $6.63 | 1.1% |
| MSFC | 4775 | 3,521 | $838,104 | $362,438 | $102.94 | 43.2% | $351,654 | $99.87 | 42.0% | $358,201 | $101.73 | 42.7% |
| PBS | 3411 | 6,082 | $40,988,331 | $524,809 | $86.29 | 1.3% | $509,193 | $83.72 | 1.2% | $518,674 | $85.28 | 1.3% |
| **Total[D]** | | **1,183,485** | **$2,923,726,964** | **$20,987,140** | **$17.73** | **0.7%** | **$21,626,946** | **$18.27** | **0.7%** | **$20,868,238** | **$17.63** | **0.7%** |

[A] Sustainment is the average annual sum of preventative maintenance, unscheduled maintenance, and major repair and replacement tasks.
[B] Size is the approximate GSFT associated with the wind tunnel from site inspections. GSFT of entire property may exceed inspection sample.
[C] CRV is the Current Replacement Value of the entire property and may exceed the value of the inspected area.
[D] All costs expressed in $2012.

## Operations Costs

Estimates of twenty operations costs are shown in Table 9 and 10. Costs were broken out into two tables, the typical MARS chart of accounts and the unique utilities associated with NASA Wind Tunnels. In total, the CBRE | Whitestone operations requirements for the selected Wind Tunnels are an annual average of $10.1 million, or 0.3 percent of replacement value. Note that in commercial accounting M&R (sustainment) is often included as an operating cost, but is reported separately above.

Table 9 shows costs for nine operations types included in MARS.

**Table 9. Annual Estimates of CBRE | Whitestone Operations Costs by Site, Wind Tunnels**

| | | | | CBRE \| Whitestone Operations Types[A] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Property No. | GSFT[B] | CRV[C] | Custodial | Grounds | Management | Pest Control | Refuse | Road Clearance | Security | Telecom | Water/ Sewer[D] | Total Costs | Per GSFT | Percent CRV |
| ARC | N206/N206A | 36,364 | $253,246,932 | $4,541 | $12,533 | $633,117 | $5,407 | $603 | $0 | $28,413 | $27,670 | $0 | $712,284 | $19.59 | 0.3% |
| ARC | N215 | 28,763 | $36,488,779 | $3,592 | $9,913 | $91,222 | $4,277 | $477 | $0 | $22,474 | $21,886 | $0 | $153,841 | $5.35 | 0.4% |
| ARC | N221/N221B | 171,129 | $529,305,708 | $21,371 | $58,981 | $1,323,264 | $25,444 | $2,838 | $0 | $133,712 | $130,215 | $0 | $1,695,824 | $9.91 | 0.3% |
| ARC | N227A/N227B/N227C | 53,580 | $322,857,273 | $6,691 | $18,467 | $807,143 | $7,966 | $889 | $0 | $41,865 | $40,770 | $0 | $923,790 | $17.24 | 0.3% |
| GRC | 11/170 | 32,501 | $60,139,291 | $3,541 | $6,817 | $150,348 | $2,555 | $129 | $2,603 | $24,796 | $24,730 | $4,535 | $220,054 | $6.77 | 0.4% |
| GRC | 37 | 7,479 | $6,608,331 | $713 | $1,572 | $16,521 | $589 | $30 | $599 | $12,761 | $7,203 | $17,106 | $57,094 | $7.63 | 0.9% |
| GRC | 39/53/54/57/61 | 119,514 | $106,691,109 | $13,020 | $25,066 | $266,728 | $9,396 | $347 | $9,548 | $91,180 | $90,940 | $56,994 | $563,219 | $4.71 | 0.5% |
| GRC | 85/87/88/90/113/114 | 170,941 | $297,274,694 | $18,623 | $35,852 | $743,187 | $13,439 | $680 | $13,691 | $130,415 | $130,072 | $82,592 | $1,168,549 | $6.84 | 0.4% |
| LaRC | 1212C | 51,354 | $90,413,562 | $4,888 | $11,129 | $226,034 | $5,304 | $732 | $312 | $38,609 | $39,076 | $0 | $326,083 | $6.35 | 0.4% |
| LaRC | 1236 | 79,745 | $393,554,794 | $7,591 | $17,282 | $983,887 | $8,236 | $1,136 | $484 | $59,953 | $60,679 | $0 | $1,139,248 | $14.29 | 0.3% |
| LaRC | 1242 | 9,276 | $13,304,480 | $883 | $2,010 | $33,261 | $958 | $132 | $56 | $6,974 | $7,058 | $0 | $51,333 | $5.53 | 0.4% |
| LaRC | 1247D | 100,360 | $141,019,520 | $8,360 | $21,797 | $352,549 | $10,382 | $1,430 | $609 | $168,745 | $96,656 | $0 | $660,528 | $6.58 | 0.5% |
| LaRC | 1251 | 134,535 | $308,493,730 | $12,806 | $29,156 | $771,234 | $13,894 | $1,917 | $817 | $101,145 | $102,370 | $0 | $1,033,338 | $7.68 | 0.3% |
| LaRC | 1251A-15" | 24,312 | $3,161,438 | $2,025 | $5,280 | $7,904 | $2,515 | $346 | $148 | $40,878 | $23,415 | $0 | $82,511 | $3.39 | 2.6% |
| LaRC | 1251A-31" | 24,312 | $3,161,438 | $2,025 | $5,280 | $7,904 | $2,515 | $346 | $148 | $40,878 | $23,415 | $0 | $82,511 | $3.39 | 2.6% |
| LaRC | 1265 | 25,517 | $124,241,924 | $2,125 | $5,542 | $310,605 | $2,640 | $364 | $155 | $42,904 | $24,575 | $0 | $388,910 | $15.24 | 0.3% |
| LaRC | 1275 | 17,428 | $27,586,220 | $1,452 | $3,785 | $68,966 | $1,803 | $248 | $106 | $29,303 | $16,785 | $0 | $122,448 | $7.03 | 0.4% |
| LaRC | 644 | 3,767 | $6,624,391 | $359 | $816 | $16,561 | $389 | $54 | $23 | $2,832 | $2,866 | $0 | $23,900 | $6.34 | 0.4% |
| LaRC | 645 | 14,461 | $7,385,933 | $1,376 | $3,134 | $18,465 | $1,493 | $206 | $88 | $10,872 | $11,004 | $0 | $46,638 | $3.23 | 0.6% |
| LaRC | 648 | 41,771 | $134,476,694 | $3,976 | $9,052 | $336,192 | $4,314 | $595 | $254 | $31,404 | $31,784 | $0 | $417,571 | $10.00 | 0.3% |
| MSFC | 4732 | 26,773 | $15,864,288 | $2,224 | $6,635 | $39,661 | $1,790 | $406 | $61 | $46,335 | $25,785 | $0 | $122,896 | $4.59 | 0.8% |
| MSFC | 4775 | 3,521 | $838,104 | $292 | $873 | $2,095 | $235 | $53 | $8 | $6,094 | $3,391 | $0 | $13,042 | $3.70 | 1.6% |
| PBS | 3411 | 6,082 | $40,988,331 | $580 | $1,278 | $102,471 | $479 | $24 | $487 | $10,377 | $5,858 | $0 | $121,554 | $19.99 | 0.3% |
| **Total[E]** | | **1,183,485** | **$2,923,726,964** | **$123,054** | **$292,250** | **$7,309,317** | **$126,020** | **$13,983** | **$30,196** | **$1,122,917** | **$948,203** | **$161,227** | **$10,127,166** | **$8.56** | **0.3%** |

[A] CBRE | Whitestone operations include custodial, pest control, trash collection, utilities (w ater and sew er), grounds (landscape care, mow ing, and snow removal), security, telecommunications, and management.
[B] Size is the approximate GSFT associated w ith the w ind tunnel from site inspections. GSFT of entire property may exceed inspection sample.
[C] CRV is the Current Replacement Value of the entire property and may exceed the value of the inspected area.
[D] Water / Sew er use w as not available at the building level at ARC, LaRC, or MSFC.
[E] All costs expressed in $2012.

Operations requirements for the unique NASA Wind Tunnel utility types are displayed in Table 10. In total, the operations costs are an annual average of $21.2 million, or 0.7 percent of replacement value.

Table 10 shows costs for the 11 unique Wind Tunnels utilities.

**Table 10. Annual Estimates of NASA Operations Costs by Site, Wind Tunnels**

| | | | | NASA Operations Types[A] | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Property No. | GSFT[B] | CRV[C] | Building Electricity | Tunnel Electricity | Natural Gas | Steam | Process Cooling Water | 6000 PSIG Air | 450 PSIG Air | Service Air | Bldg. 64 Altitude Exh. | Bldg. 114 Altitude Exh. | IRT Chiller Plant | Total Costs | Per GSFT | Percent CRV |
| ARC | N206/N206A | 36,364 | $253,246,932 | $79,419 | $118,977 | $49,543 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $247,939 | $6.82 | 0.1% |
| ARC | N215 | 28,763 | $36,488,779 | $45,963 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $45,963 | $1.60 | 0.1% |
| ARC | N221/N221B | 171,129 | $529,305,708 | $150,008 | $2,141,451 | $50,830 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $2,342,289 | $13.69 | 0.4% |
| ARC | N227A/N227B/N227C | 53,580 | $322,857,273 | $2,365,858 | $0 | $4,432 | $0 | $232,493 | $0 | $0 | $0 | $0 | $0 | $0 | $2,602,783 | $48.58 | 0.8% |
| GRC | 11/170 | 32,501 | $60,139,291 | $27,240 | $94,637 | $0 | $139,780 | $0 | $0 | $0 | $68,342 | $0 | $0 | $26,789 | $356,789 | $10.98 | 0.6% |
| GRC | 37 | 7,479 | $6,608,331 | $3,670 | $0 | $0 | $28,265 | $178 | $0 | $1,011,456 | $0 | $7,488 | $0 | $0 | $1,051,058 | $140.53 | 15.9% |
| GRC | 39/53/54/57/61 | 119,514 | $106,691,109 | $26,526 | $2,083,200 | $146,830 | $440,812 | $684,370 | $0 | $1,137,888 | $0 | $179,712 | $0 | $0 | $4,699,338 | $39.32 | 4.4% |
| GRC | 85/87/88/90/113/114 | 170,941 | $297,274,694 | $235,459 | $1,438,400 | $61,182 | $606,300 | $277,117 | $0 | $0 | $28,476 | $0 | $572,688 | $0 | $3,219,622 | $18.83 | 1.1% |
| LaRC | 1212C | 51,354 | $90,413,562 | $145,562 | $204,868 | $0 | $117,802 | $0 | $36,724 | $0 | $0 | $0 | $0 | $0 | $504,956 | $9.83 | 0.6% |
| LaRC | 1236 | 79,745 | $393,554,794 | $456,373 | $830,277 | $0 | $207,486 | $37,047 | $237,635 | $0 | $0 | $0 | $0 | $0 | $1,768,818 | $22.18 | 0.4% |
| LaRC | 1242 | 9,276 | $13,304,480 | $8,321 | $14,221 | $0 | $21,274 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $43,816 | $4.72 | 0.3% |
| LaRC | 1247D | 100,360 | $141,019,520 | $117,617 | $0 | $0 | $296,854 | $8,518 | $4,505 | $0 | $0 | $0 | $0 | $0 | $427,496 | $4.26 | 0.3% |
| LaRC | 1251 | 134,535 | $308,493,730 | $292,491 | $569,022 | $0 | $338,503 | $89,442 | $13,372 | $0 | $0 | $0 | $0 | $0 | $1,302,830 | $9.68 | 0.4% |
| LaRC | 1251A-15" | 24,312 | $3,161,438 | $117,617 | $0 | $0 | $296,854 | $8,518 | $7,299 | $0 | $0 | $0 | $0 | $0 | $430,290 | $17.70 | 13.6% |
| LaRC | 1251A-31" | 24,312 | $3,161,438 | $117,617 | $0 | $0 | $296,854 | $8,518 | $1,711 | $0 | $0 | $0 | $0 | $0 | $424,702 | $17.47 | 13.4% |
| LaRC | 1265 | 25,517 | $124,241,924 | $53,282 | $0 | $24,452 | $84,638 | $0 | $112,771 | $0 | $0 | $0 | $0 | $0 | $275,142 | $10.78 | 0.2% |
| LaRC | 1275 | 17,428 | $27,586,220 | $11,861 | $0 | $13,332 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $25,193 | $1.45 | 0.1% |
| LaRC | 644 | 3,767 | $6,624,391 | $13,103 | $0 | $5,855 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $18,958 | $5.03 | 0.3% |
| LaRC | 645 | 14,461 | $7,385,933 | $13,103 | $0 | $22,485 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $35,588 | $2.46 | 0.5% |
| LaRC | 648 | 41,771 | $134,476,694 | $218,965 | $768,177 | $71,224 | $0 | $36,300 | $84,439 | $0 | $0 | $0 | $0 | $0 | $1,179,104 | $28.23 | 0.9% |
| MSFC | 4732 | 26,773 | $15,864,288 | $28,898 | $0 | $0 | $9,122 | $0 | $1,711 | $0 | $0 | $0 | $0 | $0 | $39,731 | $1.48 | 0.3% |
| MSFC | 4775 | 3,521 | $838,104 | $2,331 | $0 | $0 | $1,200 | $0 | $7,299 | $0 | $0 | $0 | $0 | $0 | $10,831 | $3.08 | 1.3% |
| PBS | 3411 | 6,082 | $40,988,331 | $75,888 | $0 | $8,692 | $0 | $0 | $13,403 | $0 | $0 | $0 | $0 | $0 | $97,983 | $16.11 | 0.2% |
| **Total[D]** | | **1,183,485** | **$2,923,726,964** | **$4,607,174** | **$8,263,230** | **$458,856** | **$2,885,745** | **$1,382,503** | **$520,872** | **$2,149,344** | **$96,818** | **$187,200** | **$572,688** | **$26,789** | **$21,151,218** | **$17.87** | **0.7%** |

[A] NASA Operations include utilities (electricity, natural gas, and steam), process cooling w ater, chiller w ater, high pressure air, service air, and altitude exhaust.
[B] Size is the approximate GSFT associated w ith the w ind tunnel from site inspections. GSFT of entire property may exceed inspection sample.
[C] CRV is the Current Replacement Value of the entire property and may exceed the value of the inspected area.
[D] All costs expressed in $2012.

Overall, the total operations requirements for the selected Wind Tunnels inventory are an average annual $31.3 million, or 1.1 percent of replacement value.

## Total O&M Costs

Estimated total annual Wind Tunnels costs are shown in Table 11. A combination of maintenance and repair (sustainment) and operations, these costs represent an annual average for the next 50 years. Total costs are an estimated $52.1 million per year, or 1.8 percent of replacement value.

**Table 11. Total Annual Costs by Site, Wind Tunnels**

| Site | Property No. | GSFT[A] | CRV[B] | O&M Estimates: 50-Year Avg. Sustainment[C] | O&M Estimates: Annual Operations[D] | Total Costs | Per GSFT | Percent CRV |
|---|---|---|---|---|---|---|---|---|
| ARC | N206/N206A | 36,364 | $253,246,932 | $975,942 | $960,223 | $1,936,164 | $53.24 | 0.8% |
| ARC | N215 | 28,763 | $36,488,779 | $716,707 | $199,804 | $916,511 | $31.86 | 2.5% |
| ARC | N221/N221B | 171,129 | $529,305,708 | $7,029,829 | $4,038,113 | $11,067,942 | $64.68 | 2.1% |
| ARC | N227A/N227B/N227C | 53,580 | $322,857,273 | $1,524,909 | $3,526,574 | $5,051,482 | $94.28 | 1.6% |
| GRC | 11/170 | 32,501 | $60,139,291 | $624,761 | $576,843 | $1,201,604 | $36.97 | 2.0% |
| GRC | 37 | 7,479 | $6,608,331 | $167,314 | $1,108,152 | $1,275,466 | $170.54 | 19.3% |
| GRC | 39/53/54/57/61 | 119,514 | $106,691,109 | $1,201,464 | $5,262,556 | $6,464,021 | $54.09 | 6.1% |
| GRC | 85/87/88/90/113/114 | 170,941 | $297,274,694 | $2,390,914 | $4,388,171 | $6,779,085 | $39.66 | 2.3% |
| LaRC | 1212C | 51,354 | $90,413,562 | $993,794 | $831,039 | $1,824,833 | $35.53 | 2.0% |
| LaRC | 1236 | 79,745 | $393,554,794 | $477,021 | $2,908,066 | $3,385,087 | $42.45 | 0.9% |
| LaRC | 1242 | 9,276 | $13,304,480 | $59,628 | $95,149 | $154,777 | $16.69 | 1.2% |
| LaRC | 1247D | 100,360 | $141,019,520 | $233,886 | $1,088,023 | $1,321,910 | $13.17 | 0.9% |
| LaRC | 1251 | 134,535 | $308,493,730 | $655,904 | $2,336,169 | $2,992,073 | $22.24 | 1.0% |
| LaRC | 1251A-15" | 24,312 | $3,161,438 | $148,082 | $512,800 | $660,882 | $27.18 | 20.9% |
| LaRC | 1251A-31" | 24,312 | $3,161,438 | $357,057 | $507,212 | $864,270 | $35.55 | 27.3% |
| LaRC | 1265 | 25,517 | $124,241,924 | $978,447 | $664,052 | $1,642,499 | $64.37 | 1.3% |
| LaRC | 1275 | 17,428 | $27,586,220 | $204,823 | $147,640 | $352,464 | $20.22 | 1.3% |
| LaRC | 644 | 3,767 | $6,624,391 | $19,876 | $42,858 | $62,734 | $16.65 | 0.9% |
| LaRC | 645 | 14,461 | $7,385,933 | $119,255 | $82,226 | $201,481 | $13.93 | 2.7% |
| LaRC | 648 | 41,771 | $134,476,694 | $934,166 | $1,596,675 | $2,530,841 | $60.59 | 1.9% |
| MSFC | 4732 | 26,773 | $15,864,288 | $177,583 | $162,627 | $340,210 | $12.71 | 2.1% |
| MSFC | 4775 | 3,521 | $838,104 | $358,201 | $23,872 | $382,073 | $108.51 | 45.6% |
| PBS | 3411 | 6,082 | $40,988,331 | $518,674 | $219,537 | $738,211 | $121.38 | 1.8% |
| **Total[E]** | | **1,183,485** | **$2,923,726,964** | **$20,868,238** | **$31,278,384** | **$52,146,622** | **$44.06** | **1.8%** |

[A] Size is the approximate GSFT associated w ith the w ind tunnel from site inspections. GSFT of entire property may exceed inspection sample.
[B] CRV is the Current Replacement Value of the entire property and may exceed the value of the inspected area.
[C] Sustainment is the average annual sum of preventative maintenance, unscheduled maintenance, and major repair and replacement tasks.
[D] Operations include CBRE | Whitestone operations and NASA operations types.
[E] All costs expressed in $2012.

Included in Attachment B and C are detailed MARS reports for the two sample Glenn Research Center Wind Tunnels.

# Attachment A: Detailed Wind Tunnels Research Summary

# Wind Tunnel O & M Cost Analysis for Model Input

# Provided by
# Pete Aitcheson, NASA HQ Operations and Maintenance Program Manager

## Wind Tunnel Data

As expected with any large organization, there are a number of data sources for wind tunnels and not all the data matches. Outside of visiting and analyzing every wind tunnel in the agency, which was cost prohibitive, a variety of other sources were used to determine which wind tunnels would be modeled in this project. These include:

1. The Aeronautics Test Program (ATP) was most helpful, particularly in determining which tunnels should be modeled and for providing an updated list of demolished wind tunnels. Their website was also useful to verify the wind tunnel characteristics which were used to help develop the extrapolation factors for the maintenance costs.
2. The SCAP program provided valuable information.
3. A table from Mr. Lee's manuscript on NASA Wind Tunnels.
4. The NASA Technical Facilities Catalog and the Aeronautical Facilities Catalog were also used to understand characteristics and configurations.
5. Real Property Management System (RPMS) was used for building level data.
6. Several NASA Wind Tunnel technical reports were used when more detailed information was required.
7. Discussions with on-site personnel to confirm various on-site conditions.

All the information gathered was summarized in a spreadsheet which listed:

1. Facility Number
2. Facility Size (in gross square feet)
3. Status (Active or inactive)
4. Mach Number
5. Reynolds Number
6. Flow Velocity Category (subsonic, transonic, supersonic or hypersonic)
7. Test Cell Cross Sectional Area
8. Operation (continuous or blow-down, open or closed loop)
9. Use Activity (high, medium or low)
10. Detailed Model (no for all except the 1 X 1 and the 8 X 6/9 X 15)
11. Extrapolate to 1 X 1 or the 8 X 6/9 X 15
12. Extrapolation Factor (based on test cell size flow velocity in the tunnel and configuration)
13. Notes – The notes section provides characteristics specific to each tunnel.

The spreadsheet is divided into 3 blocks:

1. Active Wind Tunnels – these are currently being used for testing at some level.
2. Inactive Wind Tunnels – these are mothballed, but could be reopened and used if a program desired to test at these conditions. For purposes of the cost study, these tunnels were modeled and medium use was assumed.

3. Propulsion Tunnels – these were not modeled, because the type of equipment and configuration appeared to deviate too far from the typical wind tunnel configuration. Arc heated, ballistic and shock facilities were also not modeled in this study.

Tunnels with multiple test cells were modeled as one tunnel since they shared common equipment.

## Extrapolation of Maintenance Costs

Maintenance costs for more common types of facilities such as office buildings or warehouses can be extrapolated to different size facilities of the same type fairly accurately on a square foot basis. The floor area of a wind tunnel has very little relevance when it comes to determining maintenance costs. Instead, the maintenance cost for a wind tunnel are more closely related to the to the power requirements of the tunnel which are in part determined by the wind speed (velocity) in the tunnel, test cell size (volume). The configuration also impacts maintenance costs such as blow down verses continuous operation (time). The following criteria were used for the initial extrapolation:

1. For subsonic and transonic continuous operation type tunnels the extrapolation was based on the 9 X 15 test section.
2. For supersonic continuous operation type tunnels the extrapolation was based on the 8 X 6 test section.
3. All blow down tunnels were extrapolated to the 1 X 1 (1NW) Wind Tunnel.

In addition, LaRC has two vertically configured tunnels; the 20 foot Vertical Spin Tunnel (VST) and the 12 Foot Low Speed Tunnel (LST). Because of their vertical configuration, they have a much smaller footprint, so the extrapolation factor was adjusted by the ratio of the area vertical tunnel to the area of the 9 X 15.

Additional features of the continuous operation type wind tunnels also impact O & M costs. The following features were also taken into account to modify the extrapolation factor in addition to 1 through 3 listed above:

1. Process cooling water requirements
2. Number of drive motors
3. Auxiliary chiller plant (IRT only)
4. Integral air dryers
5. Compressors
6. Electrolyte systems
7. Flex wall or sliding block nozzle (continuously variable)

There are other features that could be taken into account, but it was determined the remaining features either had a lower impact on overall O & M costs for most of the wind tunnels in the agency, the feature was unique to one or two facilities or modeling was more appropriate for another type of facility other than a wind tunnel. Note that most wind tunnels used an outside source of air (ie. from a plant located outside of the tunnel complex), in those cases the air was treated as a utility which is why it is not factored in at this point. The factors for each of the features used to adjust the extrapolation factor were derived from the 8 X 6/9 X 15 annual maintenance labor hours. For example, process cooling in the 8 X 6/9 X 15 consumed 6% of the total annual maintenance hours so the process cooling maintenance factor was determined to be 1.06. Below provides more detail about the maintenance factors:

1. Process cooling water requirements – If the tunnel did not use process cooling the extrapolation factor was divided by 1.06, since 6% of the total annual labor hours on the 8 X 6/9 X 15 were used to service the process cooling related components.
2. Number of drive motors – since the 8 X 6/9 X 15 has three drive motors, two motor maintenance factors were used; one factor for one drive motor and one factor for 6 or more drive motors (it was assumed having 2-4 motors was considered minimally different from 3 motors). None of the wind tunnels examined had 5 drive motors. The one motor maintenance factor is a 9% decrease in overall wind tunnel maintenance costs and the 6 plus motor maintenance factor increases overall maintenance costs by 38%.
3. Auxiliary chiller plant (IRT only) – Because the IRT relies exclusively on the IRT Chiller Plant for testing, the chiller plant maintenance was included in the IRT Extrapolation Factor. This factor was derived by dividing the Building 170 maintenance costs by an hourly rate to arrive at the annual labor hours. The percentage increase was calculated like all the other factors by dividing the chiller plant maintenance hours by the total annual maintenance hours of the 8 X 6/9 X 15 since this wind tunnel was used as the baseline. Note the energy use by the IRT Chiller Plant is taken into account in the cost of chilled water, not in the maintenance factor.
4. Air dryer - If the tunnel did not use an air dryer integral to the tunnel, the extrapolation factor was divided by 1.15, since 15% of the total annual labor hours on the 8 X 6/9 X 15 were used to service the dryer building components (Building 57).
5. Compressors - Compressors tend to be more maintenance intensive than fans. If a tunnel was equipped with a fan, the maintenance requirements were reduced by 8% (the extrapolation factor was divided by 1.08).
6. Electrolyte system - The 8 X 6/9 X 15 and the 10 X 10 use a large variable resistor system that is submerged in an electrolyte that is more maintenance intensive than an electronic variable speed drive or viable pitch fans. If a tunnel did not have this type of variable speed control, the maintenance requirements were reduced by 9% (the extrapolation factor was divided by 1.09).
7. Flex Wall or Sliding Block Nozzle – Wind tunnels equipped with continuously variable flex wall nozzles or sliding block nozzles are more maintenance intensive than those equipped with a fixed nozzle. Maintenance requirements for fixed nozzle tunnels where reduced by 5% (the extrapolation factor was divided by 1.05).

The formula used for extrapolating the *subsonic and transonic* wind tunnel maintenance costs to the 9 X 15 is as follows:

$$EF = \frac{\left(\frac{T}{T_{9x15}}\right)^{1/2} \times [1 + (C_1 + C_5)]}{[1 + (C_2 + C_3 + C_4 + C_6 + C_7 + C_8)]}$$

The formula used for extrapolating the *supersonic* wind tunnel maintenance costs to the 8 X 6 is as follows:

$$EF \quad = \frac{\left(\frac{T}{T_{8x6}}\right)^{1/2} \times (1 + C_5)}{[1 + (C_2 + C_3 + C_4 + C_6 + C_7 + C_8)]}$$

The formula used for extrapolating the *vertically configured subsonic* wind tunnel maintenance costs to the 9 X 15 is as follows:

$$EF \quad = \left\{ \frac{\left(\frac{T}{T_{9x15}}\right)^{1/2}}{[1 + (C_2 + C_3 + C_4 + C_6 + C_7 + C_8)]} \right\} X \left(\frac{A}{A_{9x15}}\right)$$

The formula used for extrapolating the blow down wind tunnel maintenance costs to the 1 X 1 is as follows:

$$EF \quad = \left(\frac{T}{T_{1x1}}\right)^{1/2}$$

Where:

*EF* = the extrapolation factor or maintenance cost multiplier for the wind tunnel being analyzed
*T* = the test cell cross sectional area for the wind tunnel being analyzed
$T_{9x15}$ = the test cell cross sectional area of the 9 X 15
$T_{8x6}$ = the test cell cross sectional area of the 8 X 6
$T_{1x1}$ = the test cell cross sectional area of the 1 X 1
*A* = facility size (gross square feet) of the wind tunnel being analyzed
$A_{9x15}$ = facility size (gross square feet) of the 9 X 15
$C_1$ = maintenance factor if the wind tunnel is equipped with an auxiliary chiller plant. The value used is 0.25, but is adjustable (see prior detailed explanation).
$C_2$ = maintenance factor if the wind tunnel does not use process cooling water. The value used is 0.06, but is adjustable (see prior detailed explanation).
$C_3$ = maintenance factor if the wind tunnel is not equipped with a dryer. The value used is 0.15, but is adjustable (see prior detailed explanation).
$C_4$ = maintenance factor if the wind tunnel has one drive motor. The value used is 0.09, but is adjustable (see prior detailed explanation).
$C_5$ = maintenance factor if the wind tunnel has 6 or more drive motors. The value used is 0.38, but is adjustable (see prior detailed explanation).
$C_6$ = maintenance factor if the wind tunnel is equipped with a fan instead of a compressor. The value used is 0.08, but is adjustable (see prior detailed explanation).
$C_7$ = maintenance factor if the wind tunnel is equipped with a solid state variable speed drive or a variable pitched fan. The value used is 0.09, but is adjustable (see prior detailed explanation).
$C_8$ = maintenance factor if the wind tunnel has a fixed nozzle. The value used is 0.05, but is adjustable (see prior detailed explanation).

Note: $C_1$ & $C_5$ were used to increase the value of the extrapolation factor, while $C_{2,\,3,\,4,\,6,\,7\,\&\,8}$ reduced the value of the extrapolation factor.

Extrapolation of custodial, refuse, grounds, pest control, road clearance, security, management, and telecommunications costs were based on facility size (gross square feet) and came from CBRE | Whitestone's MARS Facility Cost Forecast System.

## Utility Costs

*Glenn Research Center (GRC)*

Commercially provided utilities - for electricity, natural gas and water, the average of the combined annual rates for FY 2011 and FY 2012 from the NASA Energy Tracking System (NETS) were used. For some of the buildings, low voltage electricity, natural gas and steam was not metered, for these cases the utilities were estimated based on square feet and utility use of similar facilities.

Central Process System (CPS) – Compressed Air/Altitude Exhaust/Chilled Water.
Since most of the Wind Tunnels at Lewis Field use either compressed air or altitude exhaust (in most cases both) from the Central Process Systems, these commodities were treated like any other utility and unit costs were estimated. This was done using the following methods:

1. First, the full load output of all high horsepower test equipment was converted from horse power to Mega Watts (MW).
2. Since NETS does not list the high voltage equipment power consumption, it had to be calculated. The operational times for each piece of equipment was used along with the peak load multiplied a diversity value (adjustable) to arrive at the high voltage electricity consumption.
3. The building utility costs for Building 64 and Building 5 (low voltage electricity, water, sewer and natural gas) plus the operations, maintenance, janitorial, and management costs were distributed to each piece of equipment based on a combination of horsepower and average annual runtime.
4. The estimated high voltage electricity costs for each piece of equipment were added to the costs calculated in Number 3 (above).
5. The cost for 450 PSIG air, also included the cost for 40 PSIG air and 150 PSIG air and likewise, the cost for 150 PSIG air included the cost of 40 PSIG air since the low pressure systems feed into the higher pressure systems.

It is important to note that the cost of these commodities can vary significantly based on annual runtimes. The more the equipment runs, the lower the unit cost since the fixed costs of running the plant can be spread over more run hours.

Process Cooling Water – The wind tunnels at GRC use process cooling primarily to keep the equipment cool and to remove heat from the wind tunnel air stream. The process cooling is provided by 5 cooling towers in various locations around Lewis Field. The cost for process cooling water was calculated as follows:

1. The average amount of make-up water used in FY 2011 and FY 2012, assuming 3 cycles of concentration and a typical temperature difference across the towers provided a total annual flow of process cooling water.

2. The management, operations, maintenance and utility costs (including make-up water and water treatment) for all towers and pumping stations were divided by the total production of process cooling water to arrive at a unit cost.

Steam costs were also estimated at Lewis Field since it is generated on site. The steam costs accounted for the following:

1. Cost of natural gas
2. Efficiency of the plant
3. Efficiency of the distribution system
4. Operations and maintenance costs for Building 12

*Ames Research Center (ARC), Langley Research Center (LaRC) & Marshall Space Flight Center (MSFC) Utility Costs*

Like GRC, the commercially supplied costs were taken from the FY 2011 and FY 2012 NETS Data. LaRC and ARC both have process cooling. 75% of the cost of process cooling is the cost of the make-up water, so the process cooling water costs were scaled by the ratio of the ARC costs to the GRC costs and the same for the LaRC costs. Central station compressed air costs for LaRC were obtained from Operational-Phase Life Cycle Assessment of Select NASA Ground Test Facilities. Actual utility rates in NETS were used for the MSFC Tunnels except for the high pressure air for which the LaRC rate was used.

## Operational Times

Facility Operational Times: 41 – 80 hours hours/week was the range selected in the calibration sheet, which is the medium use selection in the MARS Calibration Sheet.
Wind Tunnel Run Times: these were established based on a combination of testing hours supplied by test personnel at GRC and the CPS scheduled utilities for each wind tunnel. One of three levels of operation were applied to each wind tunnel across the agency:

1. High – 600 hours of run time per year
2. Medium – 400 hours of run time per year
3. Low – 200 hours of run time per year

For the purpose of the model, all inactive facilities were assigned a default value of medium use so that ATP would be able to use these values to appropriately budget for maintenance costs should a wind tunnel become active again.

## Annual Utility Usage by Wind Tunnel

*Glenn Research Center (GRC)*

The next step to determine the annual utility costs was to break out the utility use by wind tunnel. To do this, it was necessary to establish the "typical" operational characteristics of each wind tunnel at Lewis Field. It is understood that the type CPS utilities used and drive motor loads would vary based on the type and amount of testing, it was important for estimating utility usage for each tunnel to establish a "typical" or "average" operation. This was done through discussions with the CPS dispatch personnel. This information was needed coupled with the tunnel operational times to determine the wind tunnel drive motor electricity consumption, high pressure air consumption, service air consumption and altitude exhaust consumption for the 1X1, IRT, 8X6/9X15 and 10X10.

The next step was to estimate the process cooling water consumption for each tunnel. All the wind tunnels modeled at Lewis Field except the IRT used process cooling water in the operation. The 1X1 used process cooling water for cooling the hydraulic oil and for the spray cooler. The 8X6/9X15 and 10X10 used process cooling water for electrolyte cooling, motor cooling, oil cooling, dryer cooling and wind tunnel air stream cooling. While on site, pipe sizes were recorded, pipe flow velocities were assumed based on pipe size and standard design practice, then, flow rates were calculated. The flow rates were multiplied by a diversity factor (adjustable) and wind tunnel operational time to get total process water consumed annually per wind tunnel.

Finally, the building utilities, drive motor electricity consumption, CPS utilities and process cooling water consumption was summed up to determine the total annual utility usage for each wind tunnel by utility.

As mentioned in the beginning of this section, where there were gaps in building utility information (low voltage electricity, steam and natural gas), those annual consumption numbers were estimated. Building utilities for the 1X1 had to be estimated by square foot since it only occupies a portion of Building 37. Utilities were also estimated for Buildings 61 and 113 (8X6/9X15 and 10X10 Model Shops) since they were not individually metered. Steam was not metered in any of the facilities, so all those values were estimated using the steam consumption values per square foot from another facility at Lewis Field.

The utilities for the Hypersonic Test Facility (HTF) at Plum Brook Station (PBS) included estimates for the high pressure air (based on the amount of air moved and runtime) and the 3 MW heaters as well as the building utilities. The LaRC cost for the high pressure air was used for the HTF. The building utilities are actuals and are a little low since the facility is currently inactive.

*Ames Research Center (ARC)*

The utilities estimated for the Unitary Wind Tunnel at ARC were from an accompanying appendix to this original report. The utilities for the National Full Scale (NFS) – 40X80/80X120, 7X10 and 12 Foot Pressure wind tunnels were estimated by calculating the drive motor power consumption and combining the values with the rest of the building utilities which were taken from NETS.

*Langley Research Center (LaRC)*

The utilities for the 14X22 Wind Tunnel were estimated by calculating the drive motor power consumption and combining the values with the rest of the building utilities from NETS.

The 20 foot Vertical Spin Tunnel (VST), 12 foot Low Speed Tunnel (LST) and the 20” $CF_4$ Wind Tunnels used the actual metered data from NETS for annual utility usage.

The National Transonic Facility (NTF) has an LN2 plant associated with the operation and those utilities and maintenance costs are not included in this study. It was assumed the annual electricity consumption listed in NETS was for low voltage power only. The drive motor power was calculated separately. Steam and compressed air use was pulled from an accompanying appendix to this original report. Process cooling water use was calculated from the annual make-up water requirements, cycles of concentration and the average temperature difference across the tower. The utilities for the Transonic Dynamics Tunnel (TDT) were calculated in the same manner. The Unitary Plan Wind Tunnel (UPWT) utilities were also estimated in the same manner except the building utilities were split in half since the UPWT shares Building 1251 with the 31” Mach 10 and the 15” Mach 6 Wind Tunnels.

The 8 foot High Temperature Tunnel (HTT) utilities were estimated using actual utility data from NETS for natural gas and electricity. Steam and compressed air quantities were taken from an accompanying appendix to this original report.

The 0.3 Meter Cryogenic Wind Tunnel building utilities were estimated using the data out of NETS. The drive motor electricity use was calculated separately and the steam use was scaled proportionally by square foot off the actual steam usage in Building 1212C.

The 31” Mach 10 and the 15” Mach 6 Wind Tunnels share approximately one half of Building 1251 with the UPWT. The remaining utilities not applied to the UPWT were split evenly between the two tunnels except for compressed air which was scaled based on test cell area. The values used to scale the compressed air were from an accompanying appendix to this original report.

Building 1247D houses the 20” Mach 6 Wind Tunnel along with a number of other test cells. Since there was no way to separate the utilities for the 20” Mach 6 from the rest of the building it was assumed the 20” Mach 6 Tunnel used the same building utilities as the 31” Mach 10 and the 15” Mach 6 Tunnels in Building 1251. The high pressure air consumption was scaled based on test cell size.

*Marshall Space Flight Center (MSFC)*

MSFC has two inactive wind tunnels; the High Reynolds Number Wind Tunnel in Building 4775 and the Trisonic Wind Tunnel in Building 4732. For both tunnels the electricity use was taken from NETS. The steam at MSFC is supplied by the Army and not generally metered at the building level, so steam was scaled by square foot from the usage in another facility. Since these are both blow-down tunnels, the compressed air use was scaled off the LaRC 31” Mach 10 and the 15” Mach 6 Wind Tunnels compressed air use by test cell cross sectional area. As mentioned earlier, the LaRC high pressure compressed air rates were used.

## Size and Current Replacement Value (CRV)

The size and Current Replacement Value (CRV) values came from NASA’s Real Property Management System (RPMS). There were several assumptions used which are listed below:

1. The 8X6/9X15 is made up of Buildings 39, 53, 54, 57, & 61. The control room is in Building 54 and only the control room portion of Building 54 was included in the model since the rest of Building 54 is office space. The size of the control room was measured on site and is about 2900 square feet. The CRV was estimated from RS Means for computer rooms and adjusted for the Cleveland area.

2. The IRT includes the IRT refrigeration plant size and CRV since it is used exclusively for the operation of the IRT.
3. The 1X1 in housed in Building 37, but does not take up the entire building. The size was measured on site and the CRV was prorated based on the gross square feet and CRV of Building 37.
4. The 20” Mach 6 Wind Tunnel at LaRC is housed in Building 1247D with other test cells. The CRV and size listed is for the entire building.
5. The 31” Mach 10 Wind tunnel and the 15” Mach 6 HTT are both located in Building 1251A. The size and CRV listed is for the entire building.
6. FY 2012 data was used to be consistent with the previously modeled facilities.

All the other sizes and CRV’s are right out of the RPMS with no further explanation required.

## Some Final Comments

It is important to understand the limitations of a study like this; first, we performed a detailed analysis on two very different wind tunnel facilities to come up with an accurate estimate of operations and maintenance costs over the life cycle of those facilities. This is not to be confused with what NASA is spending, but rather what NASA should be spending on those facilities. This information was used to extrapolate O & M costs to 21 other wind tunnel facilities. There are vast differences between wind tunnels based on their testing capabilities and we tried to take care of these differences as best as possible with the extrapolation factors. While using test cell size and air velocity as a basis for the extrapolation may not be perfect, it turned out to be a much better fit than facility size. As mentioned earlier in the report, technical facilities are not like office space or warehouses where extrapolation by size is a pretty good fit.

Because we only had the resources to look at two facilities, the sample size and therefore the accuracy is at the lower end of the scale. Estimating O & M cost is not an accurate science and predicting failure or equipment life span is not easy. Things like environmental conditions, manufacturing processes and tolerances, quality of components, materials, workmanship, weather, installation, commissioning, quality assurance, level of preventative maintenance and predictive testing and inspection all play a part in determining how long a building system or component might last.

Finally, the costs are presented as total annual costs, cost per Gross Square Foot (GSF) and cost as a percentage of Current Replacement Value (CRV) of the facility. The focus should be on the total cost, not percent of CRV or cost per GSF, these numbers are for comparison purposes only. Percent of CRV or cost per GSF for wind tunnels has very little meaning since size was not used to extrapolate costs and the NASA CRV’s tend to be less accurate for technical facilities.