# ReadMe
# HVAB Performance Data

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Version History

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|---|---|
| 9/28/2023 | Initial Release |
| 9/30/2024 | v2: Added information to Tables 1 and 2 to include vortex property (PIV) data. Revised text for clarity. |

This document summarizes the performance data acquired during the HVAB hover test in the National Full-Scale Aerodynamics Complex (NFAC) 80- by 120-Foot test section (Ref. 1). Some details on data collection and processing are provided as well as a description of the spreadsheet data uploaded to the HVAB website.

## Data Summary:

A comprehensive set of data has been acquired for the hovering HVAB rotor, including rotor performance, blade deflections, transition locations, wake geometry, airloads, and vortex properties. Data were acquired in multiple configurations and phases and Refs 2-3 identify the specific run numbers for each configuration and data type. Some data, including performance, blade motions, and atmospheric conditions, were acquired for all runs and are described in this document.

During operations, a significant amount of blades-on checkout testing was conducted to evaluate the quality and repeatability of the primary measurements and to determine the best operating procedures. The two major areas that needed to be addressed were the rotor balance thermal drift and the effects of recirculation. These areas are discussed in detail in Ref. 1. Balance drift was addressed by performing a pre-heat run prior to each research run as well as additional post-processing of the data. The effects of recirculation were addressed by acquiring multiple data points over a 5-to-10 min period and averaging the repeat points to provide the best mean data. The number of points and the period over which data were acquired were dependent on the test configuration and the type of research data being acquired. Table 1 lists the nominal number of data points acquired for each data type. The baseline performance runs collected 10 data points per collective, with approximately 30 seconds between points. For the blade deflection, wake geometry, and vortex property data types, additional points were taken to match the data collection requirements for those systems. For the airloads, there was a variable number of data points recorded. The separate data system used to record the airloads data would occasionally malfunction and repeat points would be taken for both systems. At some conditions, an extra valid point was recorded, or issues would be noticed later, resulting in fewer than 10 points. In this case, the number of data points used for the performance data will match the number of working points for airloads.

| Data Type | Data pts per COLL |
|---|---|
| Performance Only | 10 |
| Blade Deflections | 12 |
| Transition Locations | 10 |
| Wake Geometry | 14 |
| Airloads | 10+ |
| Vortex Properties | 10, 37 |

Table 1: Nominal data points acquired per data type.

Data Collection and Processing:

Data acquisition and initial data reduction for the HVAB test was accomplished using the NFAC Data Acquisition System (NFAC DAS). After each run the data were exported in both a raw and engineering units (EUD) format. The raw format contained only raw measured data, with no additional calculations. The EUD format contained both raw and EU data, including shunt resister data (RCAL), EU conversions, and derived parameters. Each format included complete time histories, data averaged by point, and the half peak-to-peak values of each point. The NFAC EUD data was used for day-to-day quality checks and to confirm that the systems were working correctly. The raw data were uploaded to NASA's Rotor Database Management System (RDMS), where all parameters were recomputed to generate EUD values. As the HVAB testing progressed, some updates were made to the RDMS coefficients/equations and the data reprocessed. Therefore, the RDMS serves as the source of true data for the HVAB test.

There were hundreds of channels collected during testing. Many of them were interim steps in calculations, or raw values that did not factor into important calculations. Therefore, only a small subset of data was selected for the final database. The chosen channels provide all the necessary information on the atmospheric conditions, blade motions, and performance. The selected mean EUD data for each identified data point were pulled from RDMS and input to previously configured spreadsheets for further processing.

The first spreadsheet processing step applies a thermal drift correction to every thrust and torque value. Though a pre-heat run was performed prior to all research runs, a small amount of drift was still noticeable in the data. A simple correction was applied to each run based on the point number; this method aligned well with correcting the drift by elapsed time. The formula used is shown in Equation 1. Once the thrust and torque were corrected, the performance data were recalculated, including $C_T$, $C_P$, and figure of merit.

$$F_{corrected} = F_1 + \frac{F_{end} - F_1}{P_{end} - P_1} * (P_x - P_1) \qquad 1$$

Once the performance data for each data point were updated, all data were then averaged for each condition (tip Mach number and collective). In addition to averages of all the individual parameters, the average blade motion was also computed (average of all four blades). This provides one representative pitch, flap, and lag value for each condition. During testing, there were some transducers/measurements that broke, most notably the pitch measurement on Blade 4. The spreadsheet filtered any values that seemed broken and eliminated them from the averages. These values were also manually checked. The final filtered and manually verified data were then transferred to a new spreadsheet to be uploaded to the online database.

In addition to the averages, the uncertainty for each parameter was calculated and included in the new spreadsheet. The atmospheric measurements were assumed to have a constant uncertainty based on their calibration. The uncertainties (95% confidence intervals, Eqn. 2) for the performance parameters were determined using the data point variability of the mean data (assumed the relevant calibration uncertainties were small).

$$CI = \bar{x} \pm z\frac{s}{\sqrt{n}} \tag{2}$$

This uncertainty calculation was performed individually on each of the performance parameters. The major deviations measured in the performance data were seen in both thrust and torque, meaning there was no coupling effect that needed to be considered.

The blade root motions contained both calibration uncertainties from the sensors as well as variability of the mean data. (The calibration uncertainties for the root motions can be found in the appendix of this document.) When averaging all the blade measurements, special steps were taken in the uncertainty analysis. Uncertainty of the mean pitch, flap and lag angles was computed using a two-step process. In the first step, the mean of the four blade measurements was computed. Then the 95% uncertainty bound was computed by combining the statistical uncertainty from the four blade measurements with their frozen calibration uncertainties and propagated through the mean. Next, the average of the N repeat measurements points was taken to get a final value for the average blade angle at the target collective. The uncertainty for this final measurement was calculated by combining the statistical variation between the repeated measurements of the mean, with the total uncertainties of each point (calculated in the previous step) propagated through the mean using the same formulas as the blades. The equations for this analysis are shown in Equations 3-7.

$$\bar{\mathrm{x}} = \frac{\sum_{i=1}^{N} \mathrm{x_i}}{\mathrm{N}} \tag{3}$$

$$\frac{\partial \bar{\mathrm{x}}}{\partial \mathrm{x_i}} = \frac{1}{N} \tag{4}$$

$$\mathrm{u_{bias}} = \sqrt{\sum_{\mathrm{i=1}}^{\mathrm{N}} \left(\frac{\partial \bar{\mathrm{x}}}{\partial \mathrm{x_i}} \mathrm{u_{bias}^{i}}\right)^2} = \frac{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{N}} \left(\mathrm{u_{bias}^{i}}\right)^2}}{N} \tag{5}$$

$$\mathrm{u}_{stat} = t_{(0.025,3)} \cdot \mathrm{s}_x \tag{6}$$

$$\mathrm{u_{total}} = \sqrt{\mathrm{u_{stat}^2} + \mathrm{u}_{bias}^2} \tag{7}$$

Description of Spreadsheet Data:

Separate spreadsheets of the performance data are provided, one for each of the key HVAB runs. Each spreadsheet contains two tabs, one with averaged data and one with confidence interval estimates. Each tab presents data in run sheet format (separate test conditions in each row and data in multiple columns). A common identification scheme is used to describe the condition, RxxMxxTHxx, with ‘R’ indicating the run number, ‘M’ indicating the tip Mach, and ‘TH’ indicating the collective. The data columns consist of both measured and derived parameters (both dimensional and non-dimensional). Descriptions of these parameters (including units and sign conventions) are provided in Ref. 4.

A summary of the performance data is provided in Table 2, including file names, run numbers, tip Mach numbers and available collectives. Some runs included multiple tip Mach numbers, and oftentimes repeat collective points were acquired across multiple runs. Note that test conditions for Runs 30-36 were set up on RPM rather than tip Mach number; the tip Mach number listed for these runs is only approximate.

| File Name | Run Number | Tip Mach | Collective |
|---|---|---|---|
| Run30 | 30 | 0.650 (1250 RPM) | 4-13 |
| Run34 | 34 | 0.675 (1310 RPM) | 4-14 |
| Run36 | 36 | 0.600 (1160 RPM)<br>0.650 (1250 RPM) | 4-12<br>14 |
| Run44 | 44 | 0.650 | 4-15 |
| Run46 | 46 | 0.600 | 4-14 |
| Run48 | 48 | 0.675 | 4-14 |
| Run50 | 50 | 0.650 | 8,10,12,14 |
| Run52 | 52 | 0.675 | 8,10,12,14 |
| Run54 | 54 | 0.600 | 8,10,12,14 |
| Run59 | 59 | 0.650 | 4-15 |
| Run61 | 61 | 0.600 | 4-15 |
| Run63 | 63 | 0.600<br>0.650<br>0.675 | 13<br>13,15<br>4-14 |
| Run65 | 65 | 0.600<br>0.650<br>0.675 | 10,12,14<br>4,6,8,10,12,14<br>10,12,14 |
| Run72 | 72 | 0.600 | 4-12 |
| Run77 | 77 | 0.650 | 4,6,8,10,11,12,13 |
| Runs92_95 | 92, 95 | 0.650 | 8, 10, 12, 14 |

Table 2: Research data from key performance runs

Although performance data were acquired during the photogrammetry (Runs 30, 34, 36) and pressure blade runs (Runs 72, 77), the rotor torque measurements for these runs were somewhat compromised and are not recommended for analysis validation. The photogrammetry runs had many retroreflective targets on the lower surface resulting in increased drag/torque. The pressure blade runs followed the forced transition runs, where small trip dot stickers were placed near the leading edge of the blade. Despite removing the stickers and cleaning the blades, residue was discovered near the leading edges after the performance data for Runs 72 and 77 were collected. This resulted in a small drop in performance that can be seen during these runs. This issue was resolved in later runs, and the performance data for Runs 92 and 95 are consistent with earlier runs.

## References

1. Norman, T.R., Heineck, J.T., Schairer, E.T., Schaeffler, N.W., Wagner, L.N., Yamauchi, G.K., Overmeyer, A.D., Ramasamy, M., Cameron, C.G., Dominguez, M., and Sheikman, A.L., "Fundamental Test of a Hovering Rotor: Comprehensive Measurements for CFD Validation," VFS 79th Annual Forum Proceedings, West Palm Beach, FL, May 2023. https://rotorcraft.arc.nasa.gov/Publications/files/79-2023-1166-Norman.pdf
2. "HVAB_General_Information_Readme_v2.docx", General Information page on HVAB website
3. "Data_Recommendations_v2.docx", General Information page on HVAB website
4. "HVAB_Parameter_List.xlsx", General Information page on HVAB website

## Appendix- Constants and Calibration Errors:

| Constant | Value |
|---|---|
| rotor radius (ft) | 5.54167 |
| chord (in) | 5.45 |
| solidity | 0.1033 |

Table A1: Rotor Constants

| **Flap** | ***FLAP1_AVG*** | ***FLAP2_AVG*** | ***FLAP3_AVG*** | ***FLAP4_AVG*** | |
|---|---|---|---|---|---|
| *Cal uncertainty* | 0.186 | 0.066 | 0.024 | 0.108 | |
| *Torque Bat Offset Uncertainty* | 0.190 | 0.190 | 0.190 | 0.190 | ***Total*** |
| *Total Frozen Uncertainty* | **0.27** | **0.20** | **0.19** | **0.22** | **0.11** |

| **Lag** | ***LAG1_AVG*** | ***LAG2_AVG*** | ***LAG3_AVG*** | ***LAG4_AVG*** | |
|---|---|---|---|---|---|
| *Cal uncertainty* | 0.610 | 0.206 | 0.457 | 0.899 | |
| *Torque Bat Offset Uncertainty* | 0.00 | 0.00 | 0.00 | 0.00 | ***Total*** |
| *Total Frozen Uncertainty* | **0.61** | **0.21** | **0.46** | **0.90** | **0.30** |

| **Pitch** | ***BPITCH1_AVG*** | ***BPITCH2_AVG*** | ***BPITCH3_AVG*** | ***BPITCH4_AVG*** | |
|---|---|---|---|---|---|
| *Cal uncertainty* | 0.151 | 0.147 | 0.034 | 0.143 | |
| *Blade 3 Pitch C0 Correction* | 0.00 | 0.00 | 0.13 | 0.00 | ***Total*** |
| *Total Frozen Uncertainty* | **0.15** | **0.15** | **0.13** | **0.14** | **0.07** |

Table A2: Root Motion Uncertainties