ReadMe

HVAB Performance Data

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Throughout the testing campaign, the HVAB dataset was constantly modified to improve the quality of results. Some of these changes were operational, such as performing a pre-heat run to minimize drift during research runs. Some were in the post-processing, such as choosing to average repeat points. Others still retroactively changed recorded values, such as modifying constants in the blade motion. This document serves as a supplement to the final data and documents all corrections and post-processing steps.

Data Collection:

Table 1 lists the various data collection methods utilized, as well as an acronym to describe each. The baseline run collected 10 data points per collective, with approximately 30 seconds between points. The table also details the normal number of points collected for each method. For the airloads, there was variation in the number of data points recorded. The 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
Blade Deflections	12
Transition Locations	10
Wake Geometry	14
Airloads	10+
Performance Only	10

Table 1: Data collection methods used.

The available performance data is shown in Table 2. The first name is the file name and lists the tip Mach number and available collectives. Note that some runs have a few studied tip Mach numbers, and oftentimes additional collectives were collected across a few runs. The first column in each file has the format ‘RxxMxxTHXX’, with ‘R’ indicating the run number, ‘M’ indicating the tip Mach, and ‘TH’ indicating the collective. Runs 30-36 were not set on the tip Mach, but an associated RPM. The first column uses the closest approximate tip Mach number, but it should be noted that this value is not fully accurate.

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) 0.650 (1250 RPM)	4-12 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 0.650 0.675	13 4-14 13,15
Run65	65	0.600 0.650 0.675	10,12,14 4,6,8,10,12,14 10,12,14
Run72	72	0.600	4-12
Run77	77	0.650	4,6,8,10,11,12,13

Table 2: Research data from various methods, tip Mach, and collectives

Many runs have repeat data available. For example, transition data was collected both independently and in the same run as wake geometry. However, there is a small discrepancy in the performance data, starting after Run 59. The data is consistent up to Run 59, where the forced transition studies began. The forced transition runs used small trip dot stickers near the leading edge of the blade. Despite cleaning the blades, residue was discovered near the leading edge after the performance data was collected. This resulted in a small drop in performance can be seen in Runs 72 and 77.

Data Processing:

At the end of a run, several data files were exported from the NFAC. The data was exported in both a raw format and engineering units (EUD) format. The raw format contains only data directly from the channels, with no additional calculations. The EUD format contains the raw data, along with the RCAL, calculations, and conversions. Each format is provided with the complete time history, data averaged by point, and the half peak to peak values of each point. The EUD data was used for day-to-day quality checks, to confirm that the systems were working correctly. The raw data was uploaded to RDMS, where all calculations were redone to generate the EUD values. Throughout testing, some modifications were made to the calculations. Most were small changes to various coefficients in the blade motion calculations. However, these calculations do change the final data values from the results supplied directly from the NFAC. Therefore, RDMS serves as the source of true data for the HVAB test.

There were hundreds of channels collected during testing. Many of them are interim steps in calculations, or raw values that do not factor into important calculations. Therefore, a small subset of data was selected for the final database. The chosen channels provide all the necessary information on the atmospheric conditions, blade motion, and performance. The selected EUD data is pulled from RDMS, into a previously configured spreadsheet.

First, the spreadsheet 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 based on the point number; this method aligned well with correcting the drift by elapsed time. The formula used is shown Equation 1. Once the thrust and torque are corrected, the performance data is recalculated, including C_T, C_P, and figure of merit.

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

Once the performance data is updated, all data is averaged for each collective. In addition to averages of all the individual numbers, the blade motion for each blade is also averaged. This provides one final pitch, flap, and lag value. There are some measurements that occasionally broke, most notably the pitch measurement on Blade 4. The spreadsheet filters any values that seem broken and eliminates them from the averages. These values are also manually checked. This data is what can be found in the online database.

In addition to the averages, the uncertainty for each measurement is also calculated. The atmospheric measurements are assumed to have a constant error based on their calibration. The calibration errors for the root motion and other constants can be found in the appendix of this paper. The uncertainty analysis uses a 95% confidence interval, using the equation seen in Equation 2. These values are saved into a separate spreadsheet.

$$CI = \overline{x} \pm z\frac{s}{\sqrt{n}} \quad (2)$$

This calculation is performed individually on the performance calculation. The major deviations measured in the performance data were seen in both thrust and torque, meaning there is no coupling effect that needs to be considered. The calibration uncertainty for the performance data was relatively small and was therefore excluded from analysis.

The blade root motions contain calibration errors from the sensors. When averaged all the blade measurements, special steps are taken in the uncertainty analysis. Uncertainty of the mean pitch, flap and lag angles is computed using a two-step process. In the first step, the mean of the four blade measurements is computed. Then the 95% uncertainty bound is 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 is taken to get a final value for the average blade angle at the target collective. The uncertainty for this final measurement is 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 is shown in Equations 3-6.

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \quad (3)$$

$$\frac{\partial \bar{x}}{\partial x_i} = \frac{1}{N} \quad (4)$$

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

$$u_{stat} = t_{(0.025,3)} \cdot s_x \quad (6)$$

$$u_{total} = \sqrt{u_{stat}^2 + u_{bias}^2} \quad (7)$$

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