

Unsteady Pressure Measurements on a Simplified High-Lift Configuration of the Common Research Model using Active Flow Control

Keith B. Paschal¹, Michael A. Kegerise², Dan H. Neuhart³, Mehti Koklu⁴, and John C. Lin⁵

NASA Langley Research Center, Hampton, VA 23681, USA

The High-Lift Common Research Model (CRM-HL) is a product of the NASA Advanced Air Transport Technology (AATT) Project intended to study various high-lift aerodynamic phenomena including enhanced lift, acoustic noise generation, and optimum placement of leading and trailing-edge devices. The current study was conducted in the NASA Langley 14-by 22-Foot Subsonic Tunnel (14x22) for the purpose of evaluating enhanced lift through the use of active flow control (AFC). The current paper documents the effect of sweeping-jet actuation combined with steady blowing on a simplified high-lift configuration using unsteady pressure measurements. The time-series parameters for the measurements are documented as well as the data acquisition system used to acquire the data. An uncertainty analysis will be presented in order to document the system performance and provide an estimate of the data quality. Repeatability of the data will be shown along with trends associated with model angle of attack, and also those associated with changes in the nozzle pressure ratio (NPR) of the AFC system.

I. Nomenclature

α	=	angle of attack
<i>AFC</i>	=	active flow control
<i>CRM</i>	=	common research model
<i>M</i>	=	Mach number
<i>NPR</i>	=	nozzle pressure ratio
<i>SHL</i>	=	simplified high lift

II. Introduction

The NASA Advanced Air Transport Technology (AATT) Project is evaluating the use of active flow control (AFC) to enhance the performance of high-lift systems. As a result, a high-lift version of the Common Research Model (CRM-HL) was designed, fabricated, and tested in the NASA Langley 14- by 22-Foot Subsonic Tunnel (14x22). A detailed discussion of the reasoning behind the project's efforts is laid out in Lin et al. [1]. The conventional high-lift configuration (CRM-HL) for the CRM shares leading-edge components with the AFC configuration, which deploys a simplified high-lift (SHL) flap system. The AFC configuration (CRM-SHL-AFC) is equipped with a simple-hinged

¹ Research Scientist, Flow Physics and Control Branch, MS 170

² Research Scientist, Flow Physics and Control Branch, MS 170

³ Research Scientist, Flow Physics and Control Branch, MS 170

⁴ Research Scientist, Flow Physics and Control Branch, MS 170

⁵ Senior Research Scientist, Flow Physics and Control Branch, MS 170, AIAA Associate Fellow

flap nominally deflected at 50 degrees angle of attack [1]. The focus of this paper will be on unsteady pressure measurements obtained on the CRM-SHL-AFC configuration.

III. Experimental Setup

Both the CRM-HL and CRM-SHL-AFC configurations have been tested at the NASA LaRC 14x22 [2]. This facility is a closed return, atmospheric wind tunnel with a test section that is 14.5 ft high, 21.75 ft wide, and 50 ft. long. The facility has a maximum freestream velocity of 338 ft/s which corresponds to a maximum dynamic pressure of 144 psf. The maximum unit Reynolds number is 2.2 million per foot. The testing was performed at a freestream Mach number of 0.2 and a corresponding dynamic pressure of approximately 60 psf. Detailed information concerning model dimensions, tunnel instrumentation, and additional measurement techniques such as oil-flow visualization may be found in Lin et al. [1].

The 10%-scale, semispan CRM model is shown in Figure 1a, which depicts the CRM-SHL-AFC configuration. The leading-edge devices along with the nacelle-pylon were shared with the CRM-HL configuration as a result of the modular design. The simple, hinged flap was fixed at 50 degrees angle of attack and housed ten interchangeable AFC cartridges at the flap shoulder. This allowed for the fabrication of multiple, interchangeable cartridges per spanwise location, such that distinct AFC techniques might be evaluated. The focus of this paper will be on unsteady pressure measurements made over the simple, hinged flap using the High Efficiency Low Power (HELP) Actuators. Detailed discussions on the different AFC actuators may be found in Lin et al. [1].

A detailed view of the CRM-SHL-AFC flaps is shown in Figure 1b. The ten AFC cartridges can be seen as well as the locations of the twelve piezoresistive pressure transducers. The blue tape indicates the presence of a transducer, and the channel numbers are listed beneath the tape. The twelve sensors were mounted in six rows. Each row consisted of two transducers, one located just downstream of an AFC cartridge and the second located near the trailing-edge of the flap. Even numbered channels were located downstream of the AFC cartridge, and odd channel numbers were positioned near the trailing edge. Depending on the location of the transducer, the sweeping frequency of the individual actuators could be identified in the spectra.

IV. Data Acquisition and Analysis of the Unsteady Pressures

The differential pressure transducers had a full-scale range of 5 psid and a nominal sensitivity of 550 mV/psid. Each of the sensors was referenced to facility ambient pressure. The frequency response of each transducer was flat from DC to 20 KHz as stated by the manufacturer [3]. The frequency response of each transducer was also independently verified following the procedure documented in Ref. [4]. The specific transducers employed an A-Screen, which is essentially a simple hole on the order of the sensor diameter. The physical size of each sensor is 500 micrometers by 500 micrometers. Minimal attenuation due to the finite size of the sensor is shown to exist from estimates provided by the manufacturer concerning spatial resolution [3].

The raw voltages from the pressure transducers were AC-coupled at 0.25 Hz and had a cutoff filter applied at 20 kHz using an 8th-order low pass filter. The cutoff frequency corresponded to the usable frequency bandwidth as determined by the manufacturer [3]. Satisfying the Nyquist sampling criterion resulted in a sampling frequency of 50 kHz. Each channel was digitized using a 16-bit A-to-D converter at the required sampling rate. Data from all the channels were taken simultaneously, and the total record length of each channel was set to twenty seconds resulting in one million samples per channel.

The pressure transducers were calibrated in situ with a known pressure that was applied through the reference port of the sensors. The sensors are linear devices so the calibration slope determined the sensitivity that would be applied to the voltage signal in order to generate a time history of the fluctuating pressure. Autospectral density estimates were obtained through application of the Welch method using a Hanning window with 50% overlap. The Welch method is effectively a moving average, and a total of 200 blocks were used to reduce uncertainty in the resulting spectra [5]. Each block average was comprised of 5000 data samples, and the resolution for the data set was 10 Hz.

V. Uncertainty

Uncertainty of the second-order moment pressure fluctuations will be presented in RMS form in an attempt to quantify errors in the data acquisition process. The basic assumption of the analysis was that error propagates through a system in a RMS fashion [6]. The analysis for the current data set was based on previous work that involved unsteady pressure measurements in a study investigating the flow field of a wing-fuselage juncture [7]. Findings from the current investigation show that the dominant error source was the variance of the voltage signal from the pressure transducer. This variance was estimated based on the difference between higher-order moments computed from the individual voltage signals [8]. An example of sensor uncertainties is presented in Table 1.

Table 1 RMS pressure uncertainties for $M = 0.2$, $\alpha = 16$ deg., $NPR = 2.35$.

Channel #	Calibration Slope (V/psi)	Uncertainty (%)
0	0.5508	1.64
1	0.5440	6.31
2	0.5471	1.80
3	0.5509	4.10
4	0.5523	1.40
5	0.5472	1.83
6	0.5489	1.29
7	0.5499	4.75
8	0.5517	0.86
9	0.5445	2.00
10	0.5484	0.92
11	0.5463	1.51

VI. Example Results

The effect of NPR and angle of attack was documented for the simplified high-lift configuration (CRM-SHL-AFC). The data were taken at a Mach number of 0.2 with the HELP actuators. Alpha sweeps while holding NPR constant were generated for each unsteady pressure transducer as shown in Figure 2. The broad low frequency peak shown here at approximately 80 Hz was a relatively common feature, and an indication of flow separation near the flap trailing edge. These data were taken from channel 5 at an average NPR of 2.34. In addition, NPR sweeps while holding angle of attack constant were also generated for each transducer as shown in Figure 3. Note that the average sweeping frequency of the AFC actuators in cartridge 4 is seen to vary with NPR. In this case, the average actuator frequency varies from around 500 Hz to just over 1 kHz for the highest NPR tested.

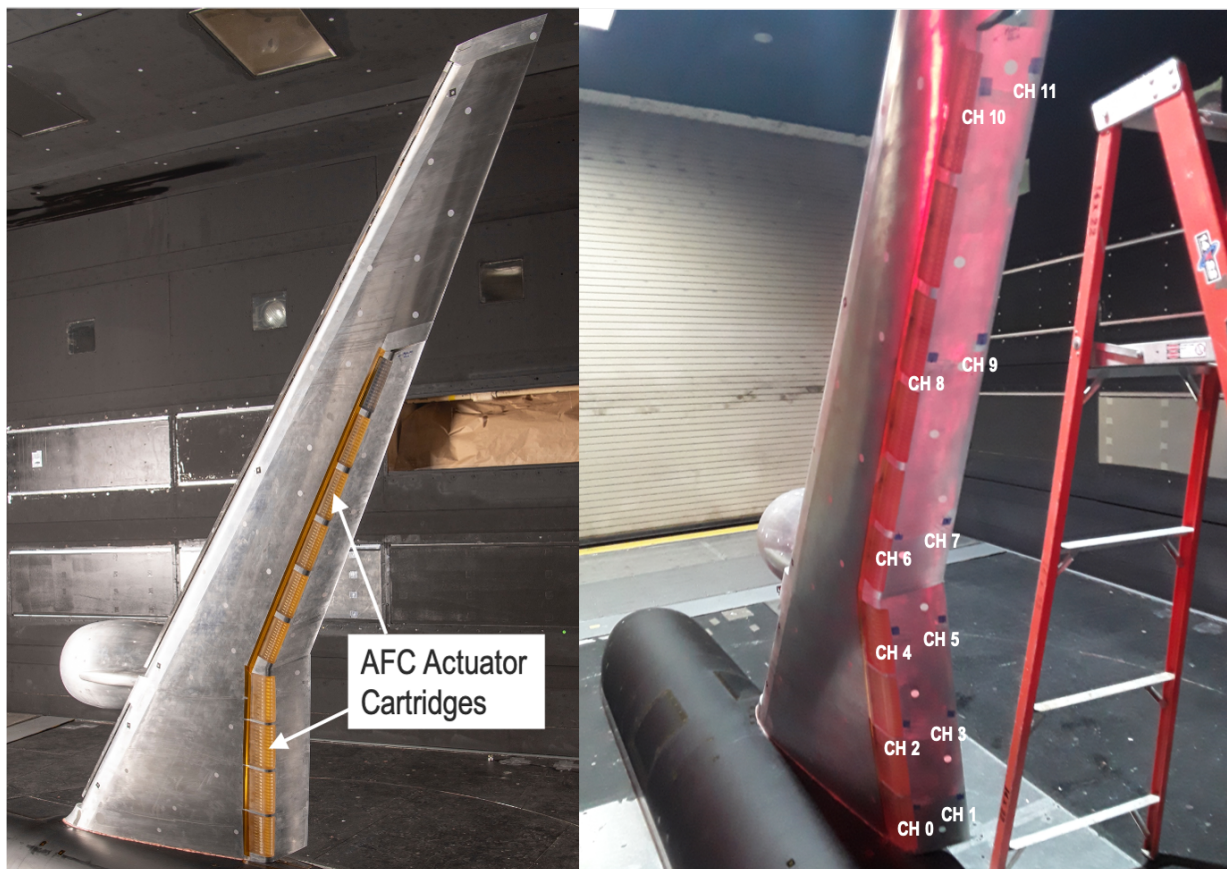
VII. Conclusion

Unsteady pressure measurements were made on the simplified high-lift configuration of the CRM in the 14x22. This configuration used ten AFC cartridges to prevent large-scale separation over the simple, hinged flaps. Each cartridge consisted of both steady blowing and sweeping-jet actuation to achieve this goal. The data acquisition process was documented and uncertainty of the unsteady pressure measurements quantified. The final paper will include a more detailed discussion of uncertainty, and repeatability of the data will be addressed. In addition, general trends in the spectra will be identified, and the effects of NPR and angle of attack addressed.

References

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(a) AFC actuator cartridges.

(b) Sensor locations on SHL flaps.

Fig. 2 CRM-SHL-AFC configuration mounted in the 14x22.

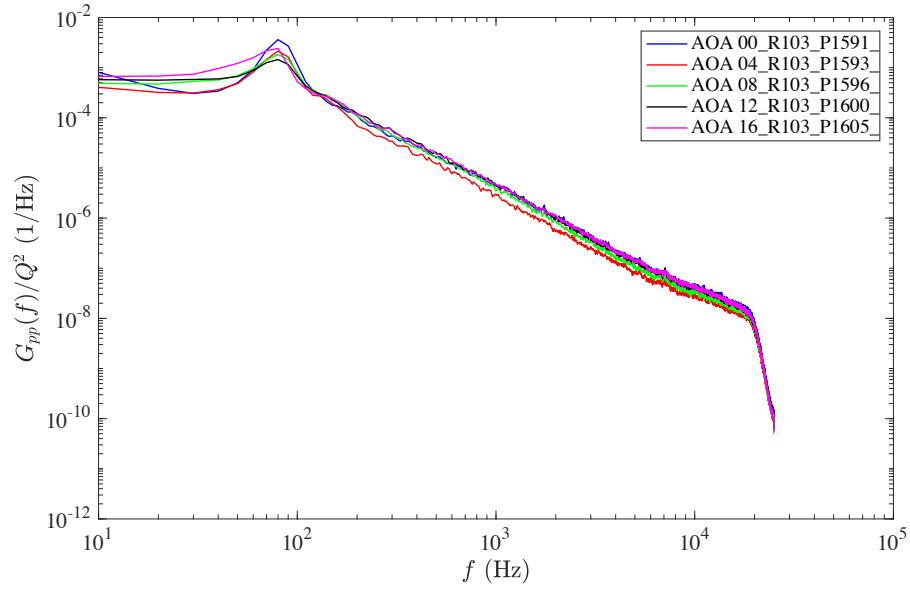


Fig. 2 Alpha sweep from channel 5 at an average NPR = 2.34.

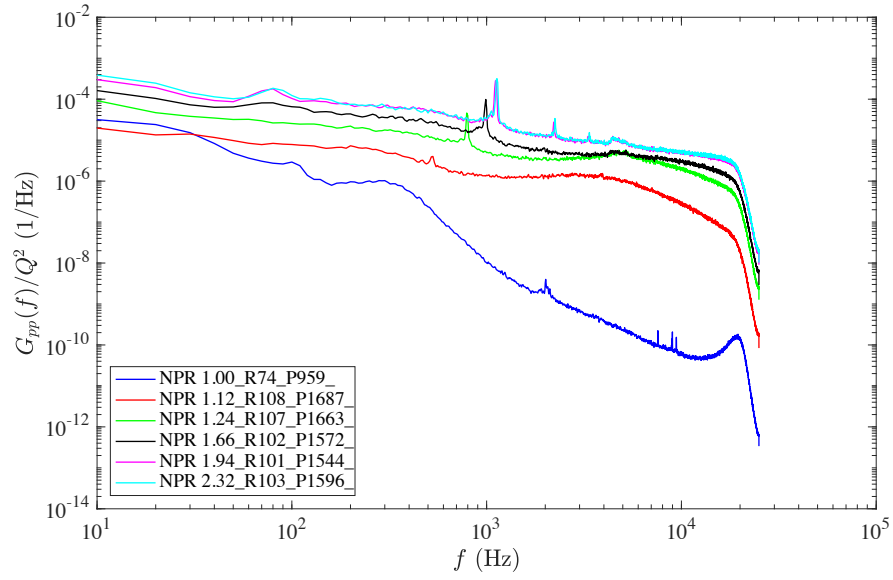


Fig. 3 NPR sweep from channel 4 at $\alpha = 8$ deg