# Stochastic Characteristics of 3D Unsteady Normal SWBL Interactions

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# *Flow Control for Normal SWBL Corner Interactions Research Objective*

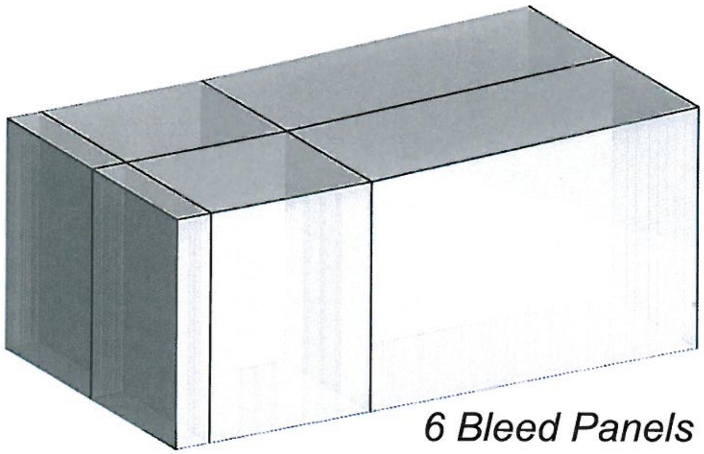
*To document and examine the characteristics of 3D unsteady normal SWBL interactions within supersonic inlets for both square and filleted corner geometries when used in conjunction with bleed and/or HyFM actuator (non-bleed) normal SWBL flow control.*

*(a) Understand and enlarge the subcritical stability margin*

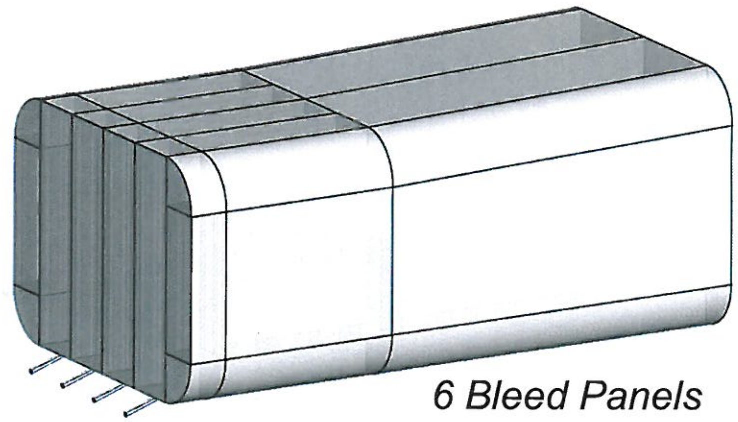
*(b) Understand and manage dynamic distortion[(1)]*

*(c) Establish the requirements for working prototype "fail safe" HyFM actuator*

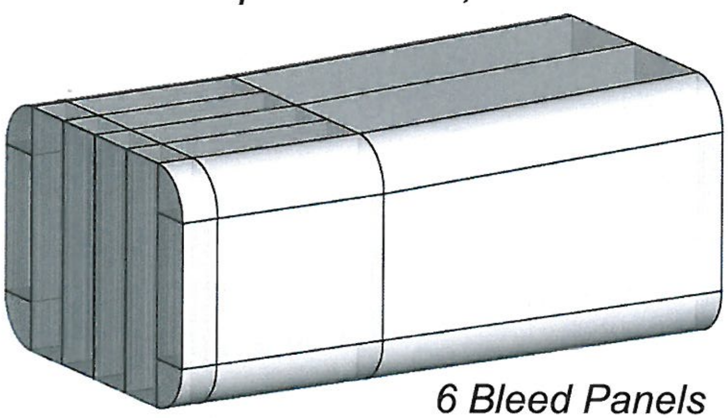
# Flow Control for Normal SWBL Corner Interactions
# HyFM Actuator Installation Geometry



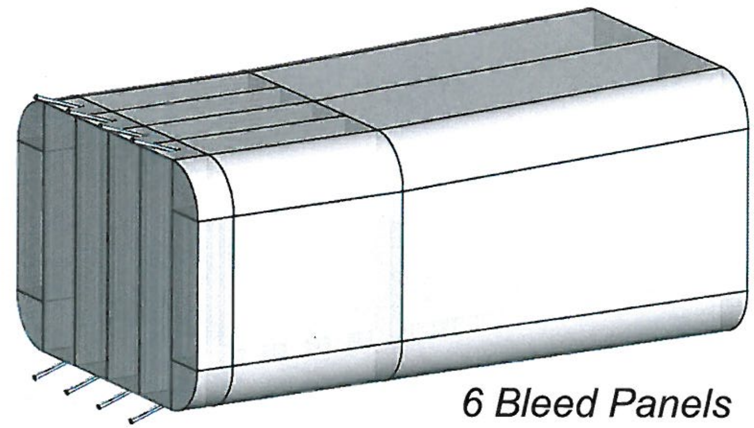

Baseline Square Corner, GRC100




Single Actuator Installation, GRC401

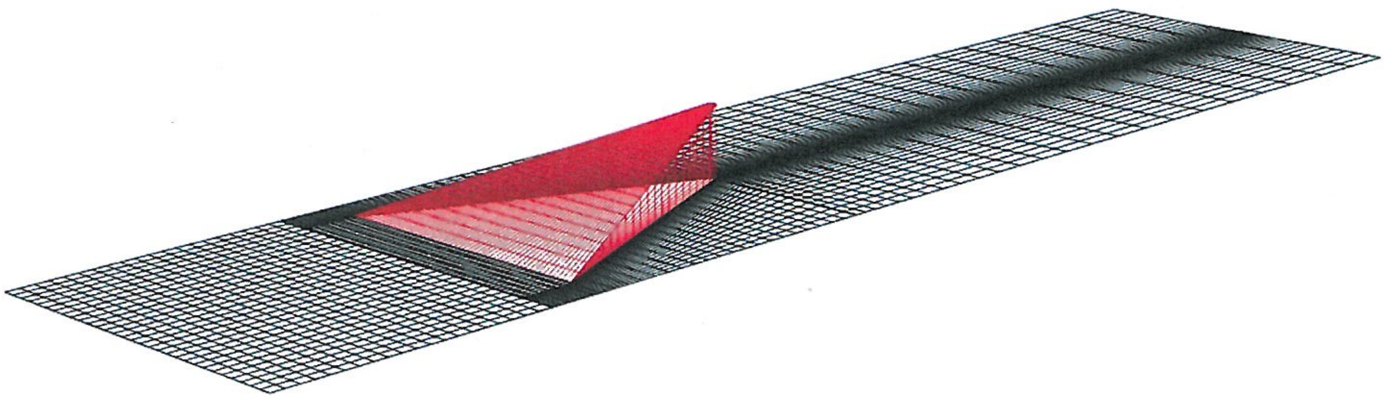



Baseline Filleted Corner, GRC201

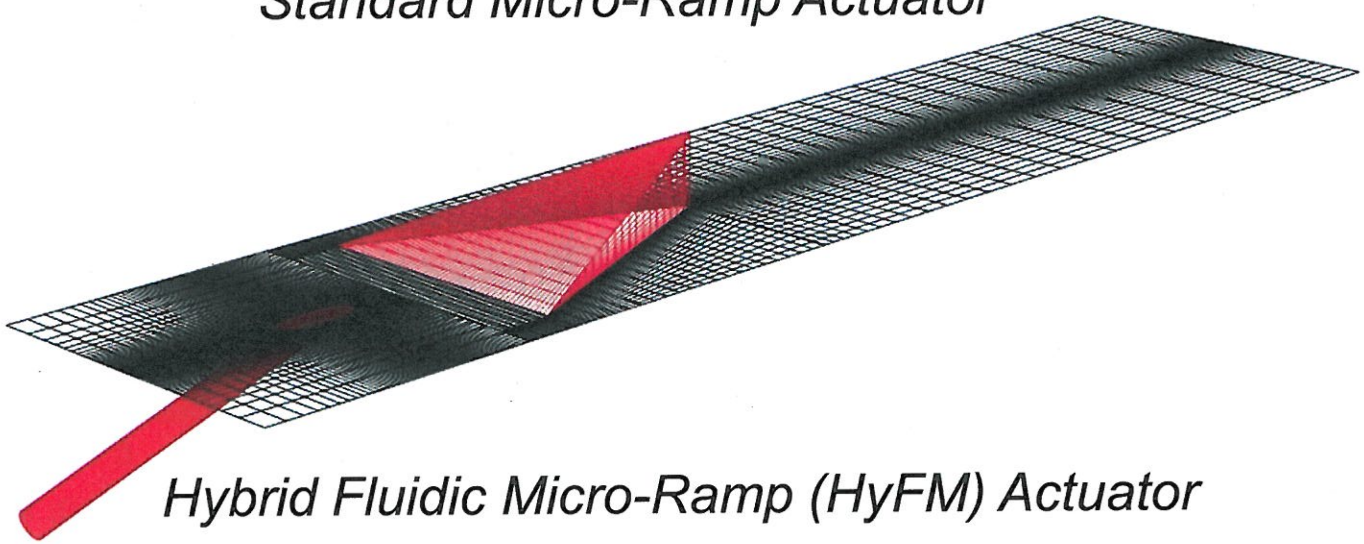



Double Actuator Installation, GRC601

# Flow Control for Normal SWBL Corner Interactions
# NASA/GRC Serial No. LEW-18322-1
# HyFM Actuator Geometry



Standard Micro-Ramp Actuator



Hybrid Fluidic Micro-Ramp (HyFM) Actuator

# Flow Control for Normal SWBL Corner Interactions Variables Held Constant

| Variable | Value |
|---|---|
| Tunnel Mach Number, $M_0$ | 1.6 |
| Tunnel Total Pressure (psf), $P_0$ | 2112.0 |
| Tunnel Total Temperature ($^oR$), $T_0$ | 517.0 |
| Nominal Tunnel Reynolds Number (per ft.), Re | $3.9 \times 10^6$ |

# Flow Control for Normal SWBL Corner Interactions
# Facility Bleed Factor Variables

| Bleed Operating Variable | Range |
|---|---|
| Left forward side bleed panel, $m_1/m_0$ | 0.0% – 2.5% |
| Left diffuser side bleed panel, $m_2/m_0$ | 0.0% – 2.5% |
| Left diffuser top bleed panel, $m_3/m_0$ | 0.0% – 2.5% |
| Right diffuser top bleed panel, $m_4/m_0$ | 0.0% – 2.5% |
| Right diffuser side bleed panel, $m_5/m_0$ | 0.0% – 2.5% |
| Right forward side bleed panel, $m_6/m_0$ | 0.0% – 2.5% |
| Total bleed mass flow ratio, $m_{bld}/m_0$ | 0.0% – 15.0% |

# *Flow Control for Normal SWBL Corner Interactions HyFM Actuator Characteristics*

| Design Variable | Value |
|---|---|
| Micro-actuator height (in.), $h$ | 0.500 |
| Micro-actuator chord length (in), $c$ | 1.375 |
| Micro-actuator lateral spacing (in.), $s$ | 1.250 |
| Micro-actuator wedge angle, (degs.), $\beta$ | 24.0 |
| % Micro-actuator jet mass flow ratio, $W_{jet}/W_o$ | 0.0183/act |
| Micro-actuator jet total pressure ratio, $P_{jet}/P_o$ | 1.0 |
| Micro-actuator jet streamwise location (in.), $X_{jet}$ | -4.2 |
| Micro-actuator jet pitch angle, (degs.), $\alpha_p$ | $20.0^0$ |

# Flow Control for Normal SWBL Corner Interactions
# Unsteady Factor Variables

| Response Variable | Nomenclature |
|---|---|
| AIP Ave. Mach Number, /rev | MFAIP |
| AIP Ave. Total Pressure Recovery, /rev | PFAIP |
| AIP Circumferential Distortion, /rev | DPC/P |
| Mach Number, Standard Deviation/rev | $S_{MAIP}$ |
| Total Pressure Recovery, Standard Deviation/rev | $S_{PFAIP}$ |
| Circumferential Distortion, Standard Deviation/rev | $S_{DPC/P}$ |

# Flow Control for Normal SWBL Corner Interactions
# DES Unsteady Factor Variables

| Time Variable | Value |
| --- | --- |
| Baseline Cases Time Step, Sec. | 1.0X10-5 |
| FyFM Actuator Cases Time Step, Sec. | 1.0X10-6 |
| CFD Data Sampling Rate, Sec | 1.0X10-4 |
| CFD Data Sampling Span, Sec (1) | 1.5X10-2 |
| Per/rev Time Span (4300 RPM), Sec. | 1.395x10-2 |
| Total Number of Data Samples | 151 |

(1) Equivalent to experimental sampling rate, $1.0 \times 10^4$ samples/sec

# Flow Control for Normal SWBL Corner Interactions
# Unsteady Time Series Methodology

- At each sampling site, i.e. every 1/10,000 of a second, the DES solution is spawned and the area average AIP total pressure recovery, and DPC/P distortion are calculate and recorded.

- Each of the four individual parameters are treated separately and a time series time history developed for the averaged properties.

- Assuming a fan speed of 4,300 RPM, a time series is developed for each of the four parameters which covers one revolution of the fan blades, i.e. 151 samples.

- For each of the individual parameters, the stochastic properties of each time series is examined to determine whether it is stationary or non-stationary, and the appropriate analysis will be applied.

- The mean of the area averaged time series is termed the "mean area averaged properties".

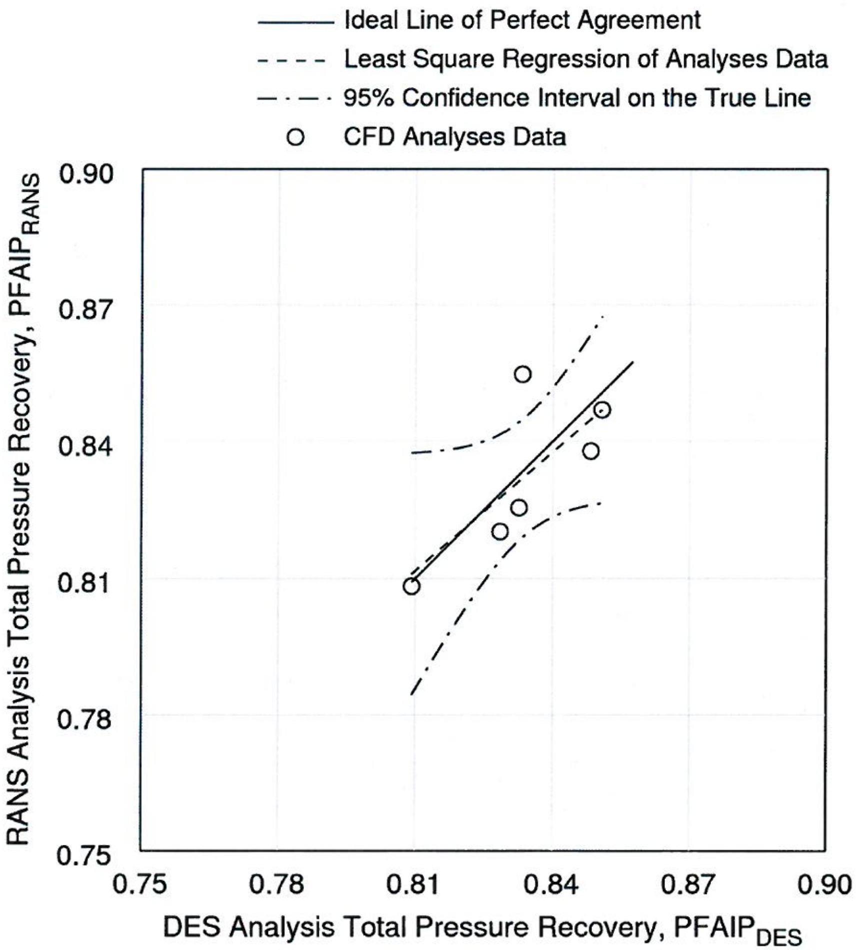
# Flow Control for Normal SWBL Corner Interactions
# 3D Steady RANS Performance Summary
# Area Averaged Properties

| Config. | Grid | $\%W_{jet}/W_o$ | PFAIP | DPC/P | $m_{bld}/m_0$ |
|---|---|---|---|---|---|
| GRC100 | $13.42 \times 10^6$ | ________ | 0.8083 | 0.2565 | 15.0% |
| GRC200 | $14.86 \times 10^6$ | ________ | 0.8202 | 0.2487 | 15.0% |
| GRC401 | $18.26 \times 10^6$ | 0.0183/act. | 0.8547 | 0.1596 | 5.0% |
| GRC402 | $18.26 \times 10^6$ | 0.0 | 0.8254 | 0.1888 | 5.0% |
| GRC403 | $18.26 \times 10^6$ | 0.0 | 0.8469 | 0.1518 | 0.0% |
| GRC601 | $18.26 \times 10^6$ | 0.0183/act. | 0.8487 | 0.14773 | 0.0% |

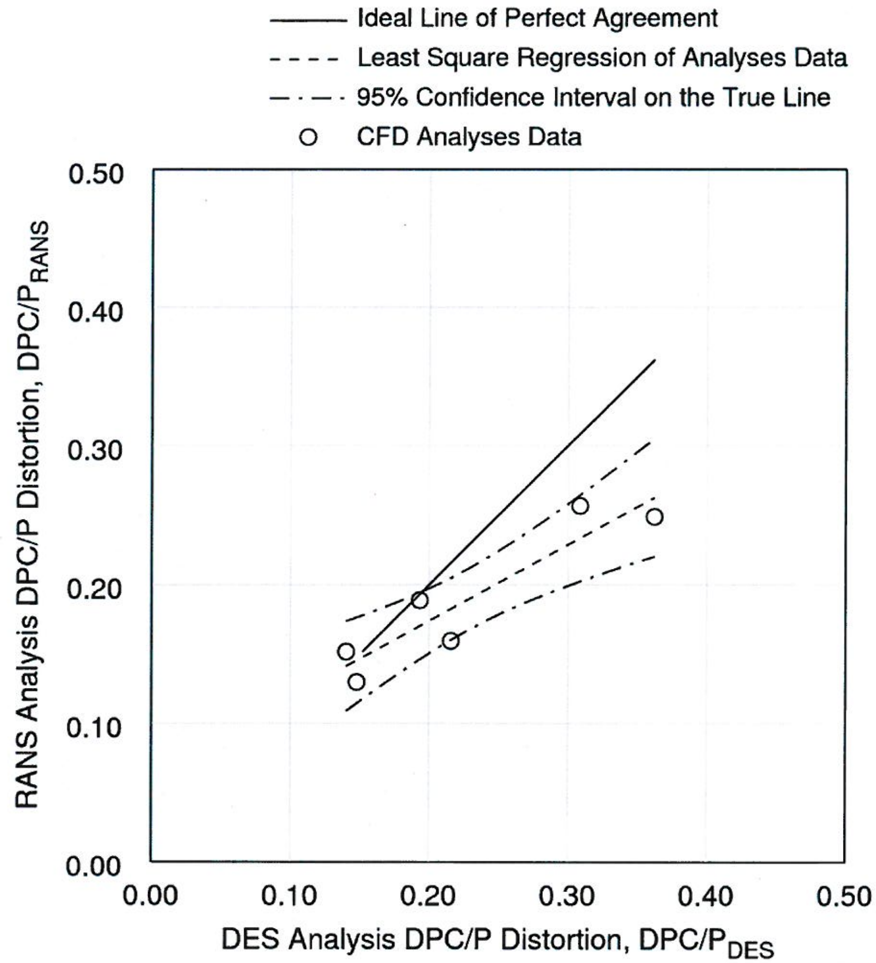
# Flow Control for Normal SWBL Corner Interactions
# 3D Unsteady DES Performance Summary
# Mean Area Averaged Properties

| Config. | Grid | $\%W_{jet}/W_o$ | PFAIP | DPC/P | $m_{bld}/m_0$ |
|---|---|---|---|---|---|
| GRC100 | $13.42 \times 10^6$ | ________ | 0.8092 | 0.3085 | 15.0% |
| GRC200 | $14.86 \times 10^6$ | ________ | 0.8285 | 0.3620 | 15.0% |
| GRC401 | $18.26 \times 10^6$ | 0.0183/act. | 0.8336 | 0.2157 | 5.0% |
| GRC402 | $18.26 \times 10^6$ | 0.0 | 0.8317 | 0.2096 | 5.0% |
| GRC403 | $18.26 \times 10^6$ | 0.0 | 0.8555 | 0.1845 | 0.0% |
| GRC601 | $18.26 \times 10^6$ | 0.0183/act. | 0.8378 | 0.13000 | 0.0% |

# Flow Control for Normal SWBL Corner Interactions Comparison of RANS and DES Analysis Stochastic Properties

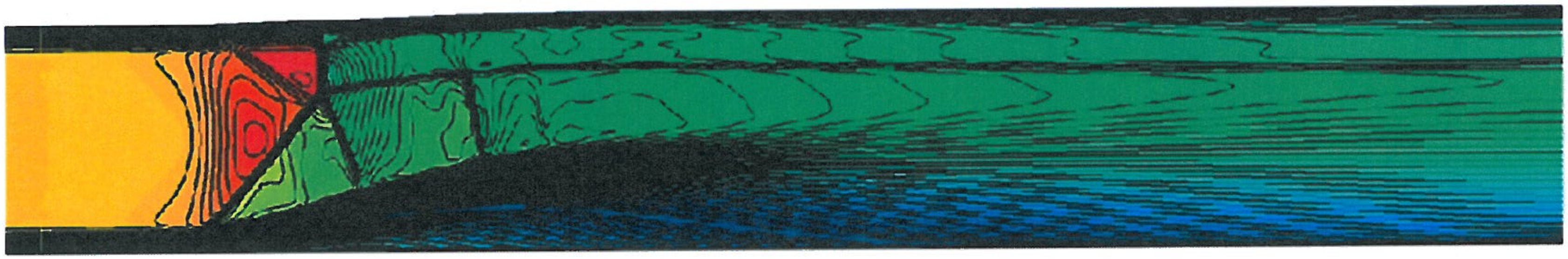



AIP Total Pressure Recovery, PFAIP




AIP Distortion, DPC/P

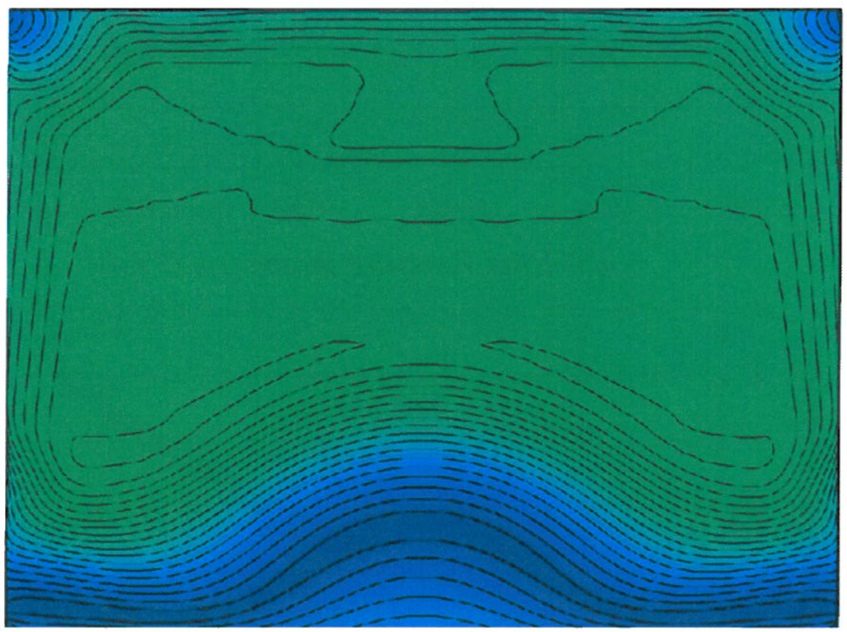
# Config. GRC100 Baseline Square Duct Geom.
# Streamwise Mach Number Contours
# Supercritical Operation
# $m_{bld}/m_0 = 15.0\%$



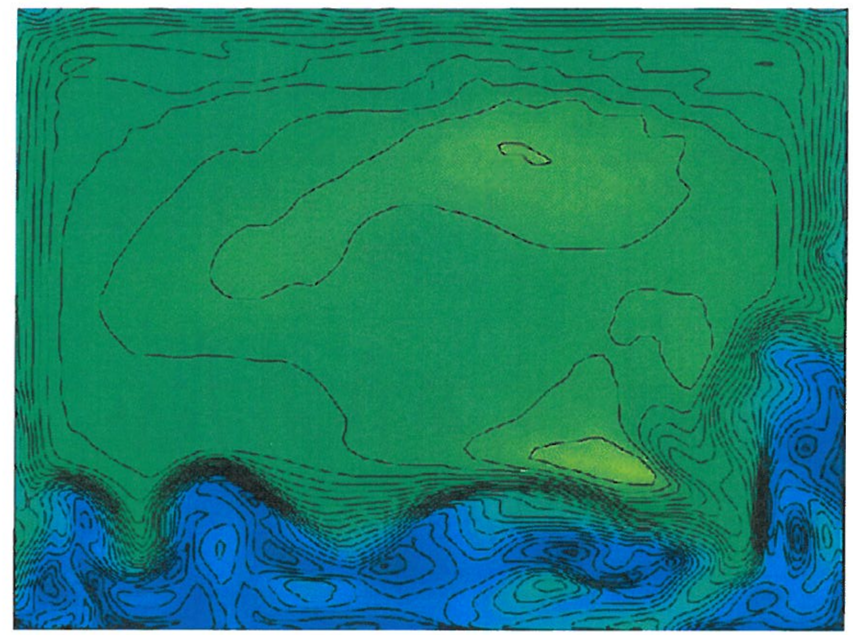
*3D Steady RANS Analysis*

*3D Unsteady DES Analysis*

# Config. GRC100 Baseline Square Duct Geom.
# AIP Mach Number Contours
# Supercritical Operation
# $m_{bld}/m_0 = 15.0\%$

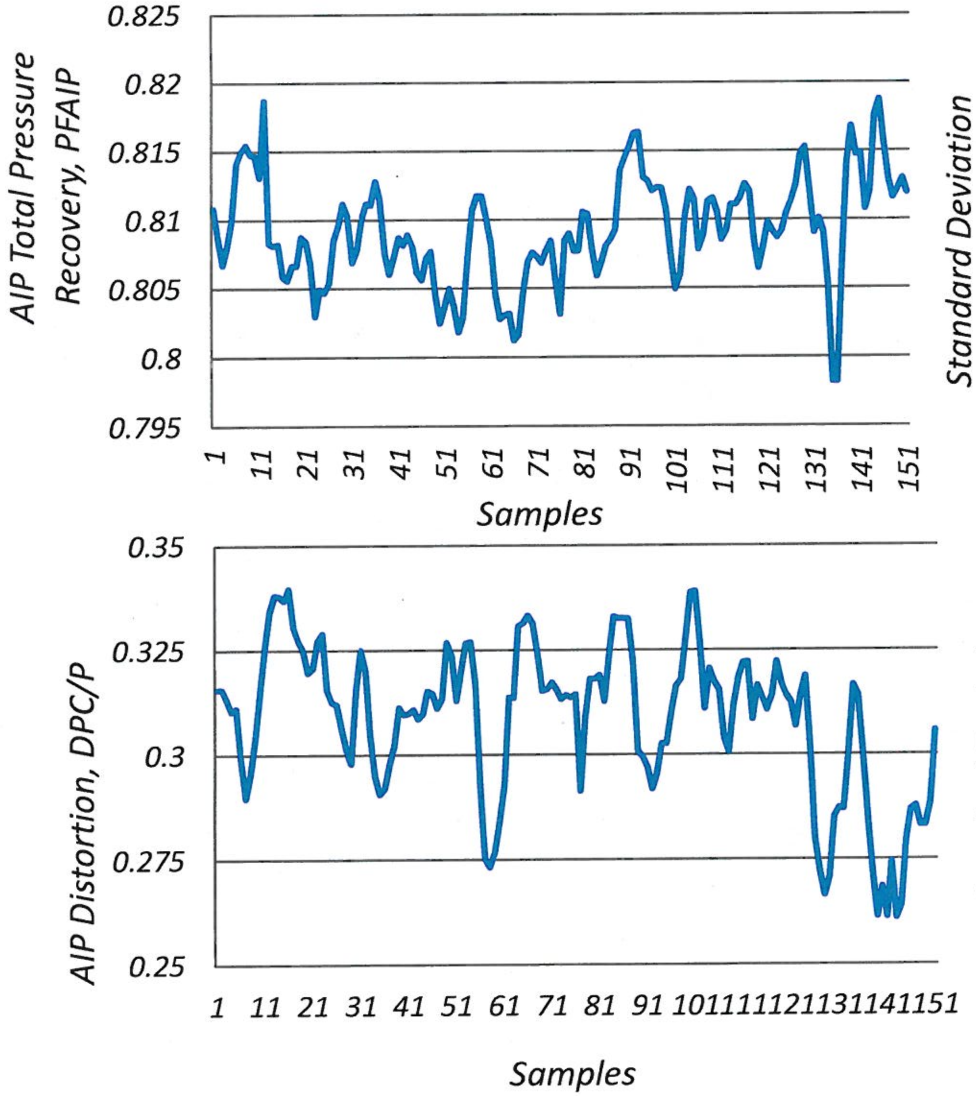


*3D Steady RANS Analysis*

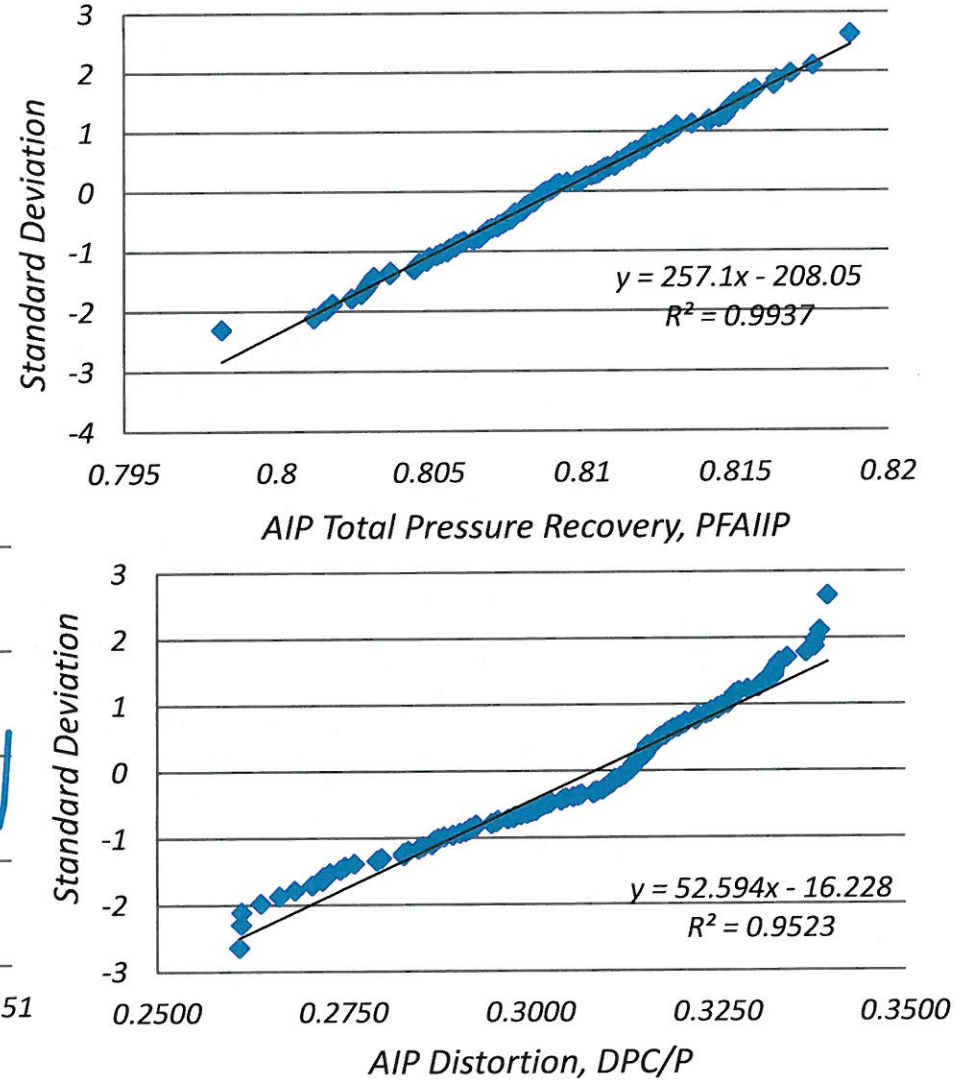


*3D Unsteady DES Analysis*

# Config. GRC100 HyFM Actuator Flow Control
# Stochastic Properties

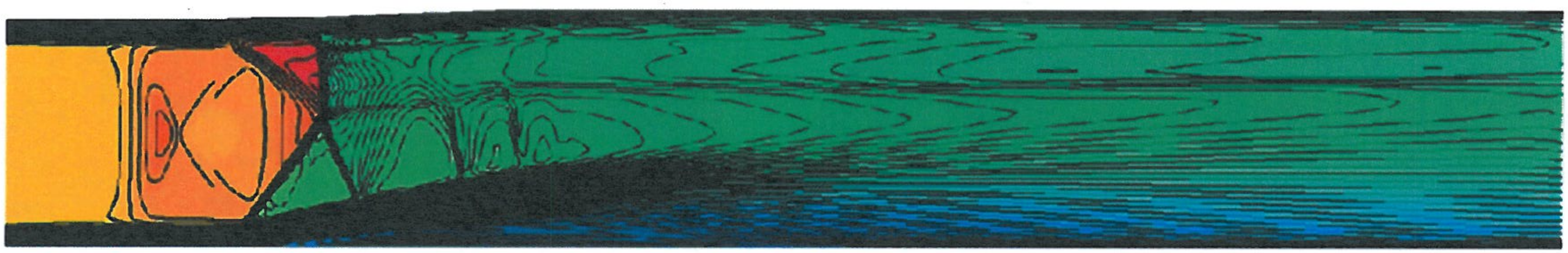



Measured Observations

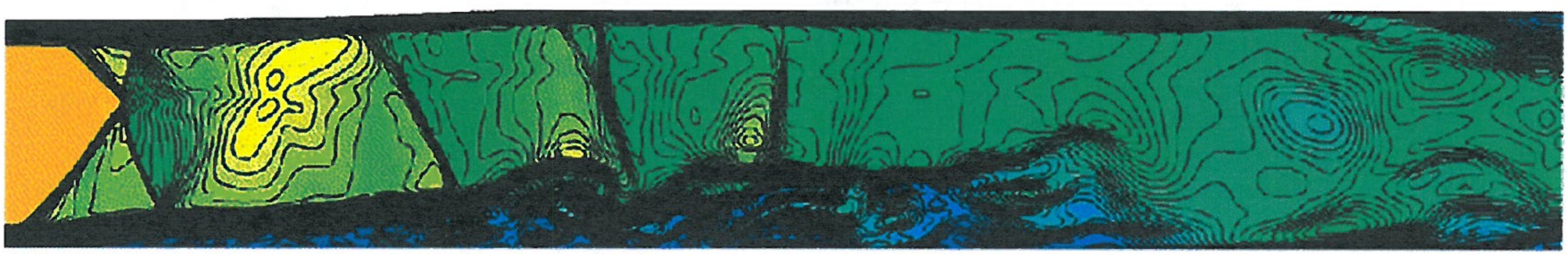



Normal Scores Diagram

# Config. GRC200 Baseline Filleted Duct Geom.
# Streamwise Mach Number Contours
# Supercritical Operation
# $m_{bld}/m_0 = 15.0\%$

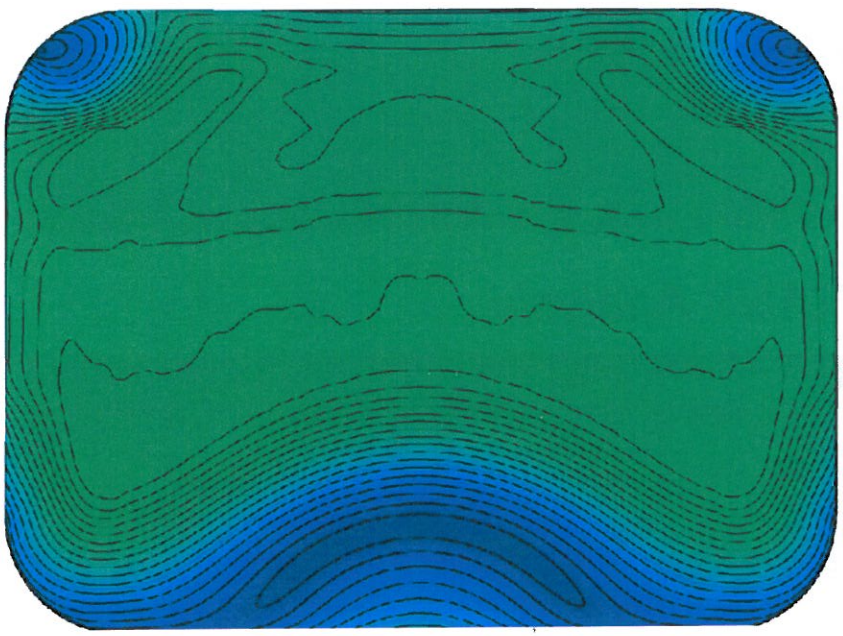


*3D Steady RANS Analysis*

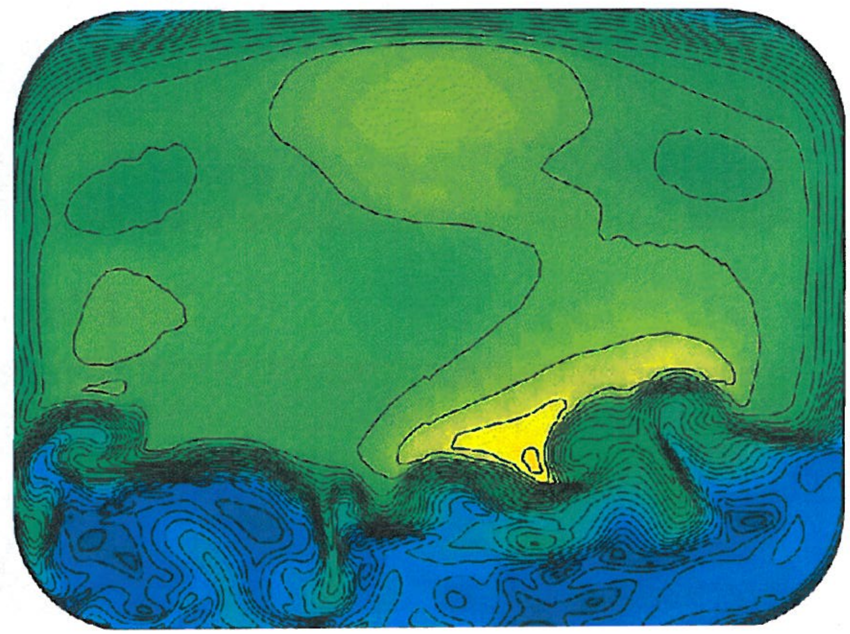


*3D Unsteady DES Analysis*

Config. GRC200 Baseline Filleted Duct Geom.
AIP Mach Number Contours
Supercritical Operation
$m_{bld}/m_0 = 15.0\%$

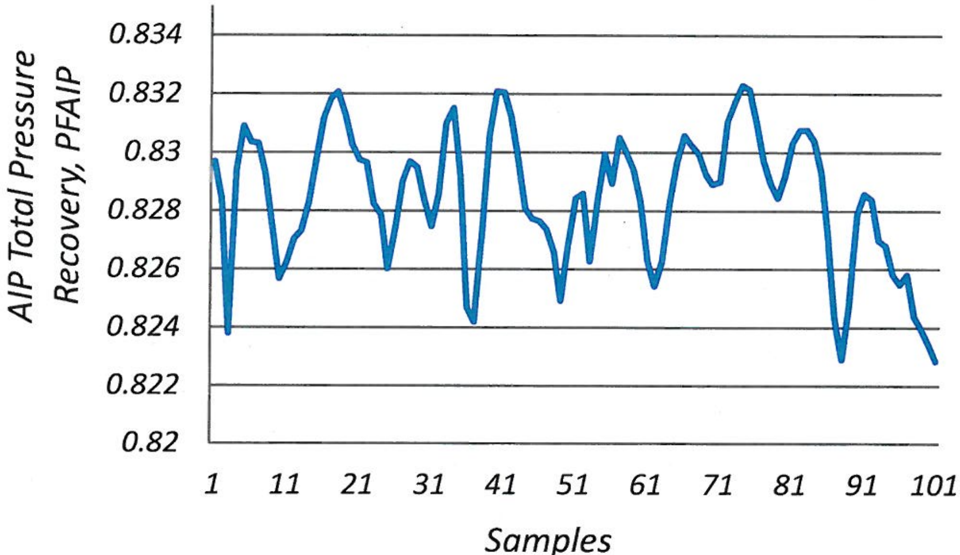


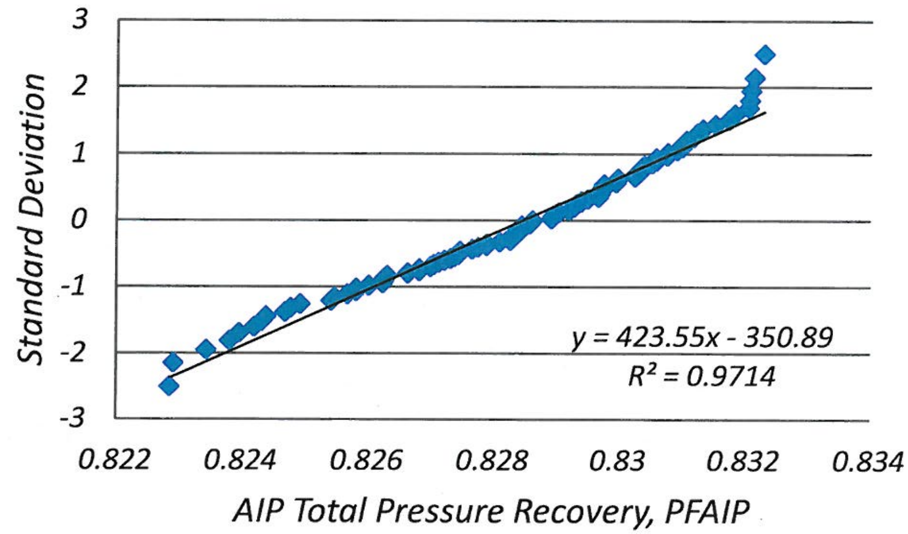
3D Steady RANS Analysis

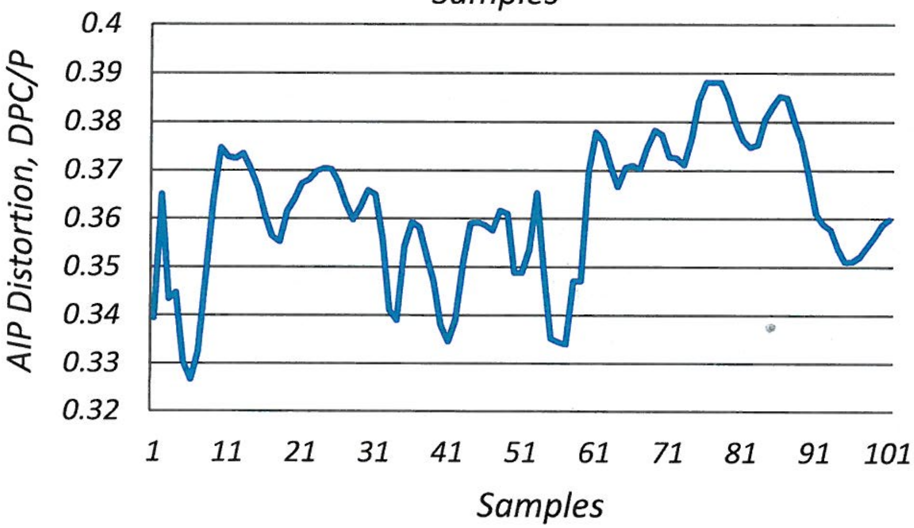


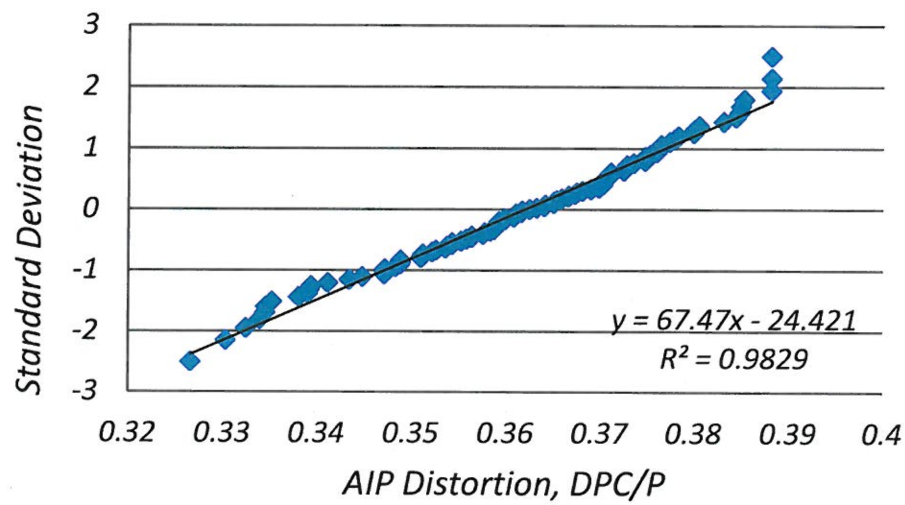
3D Unsteady DES Analysis

# Config. GRC200 HyFM Actuator Flow Control Stochastic Properties



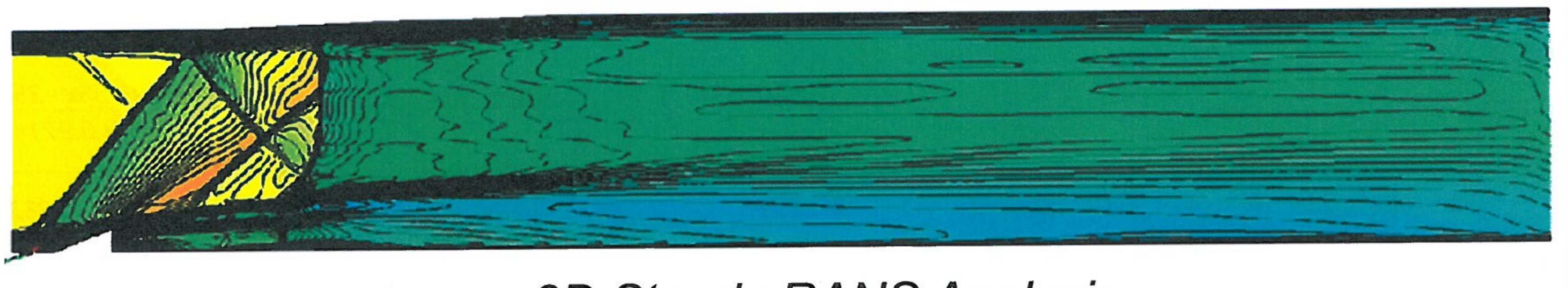




Measured Observations

Normal Scores Diagram

# Config. GRC401 HyFM Actuator Flow Control Geom.
## Streamwise Mach Number Contours
## Superitical Operation
## $m_{bld}/m_0 = 5.0\%$



*3D Steady RANS Analysis*

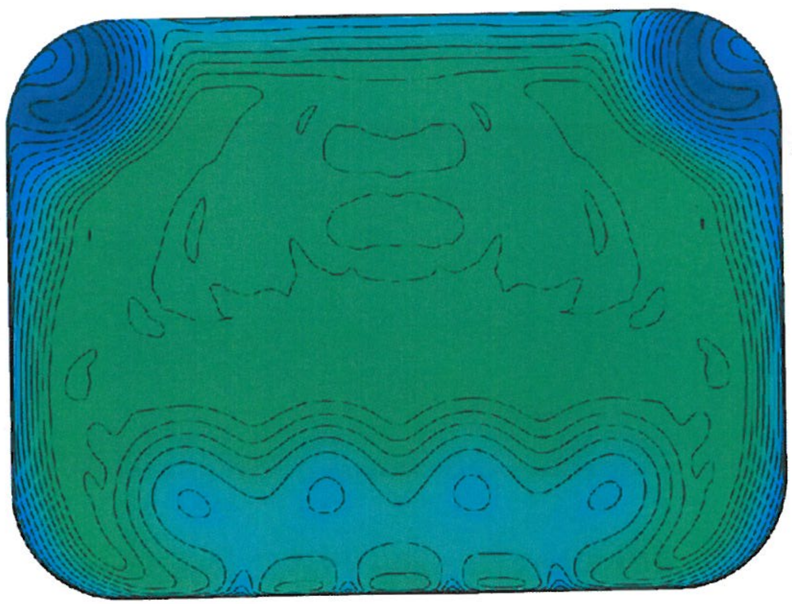
*3D Unsteady DES Analysis*

# Config. GRC401 HyFM Actuator Flow Control Geom.
# Streamwise Mach Number Contours
# Supercritical Operation
# $m_{bld}/m_0 = 5.0\%$

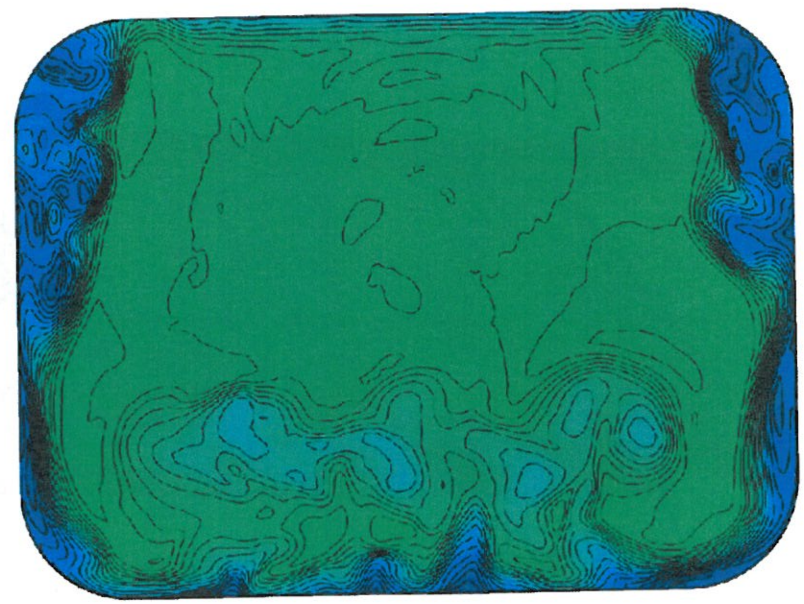
*3D Steady RANS Analysis*

*3D Unsteady DES Analysis*

# Config. GRC401 HyFM Actuator Flow Control Geom.
## AIP Mach Number Contours
## Supercritical Operation
## $m_{bld}/m_0 = 5.0\%$

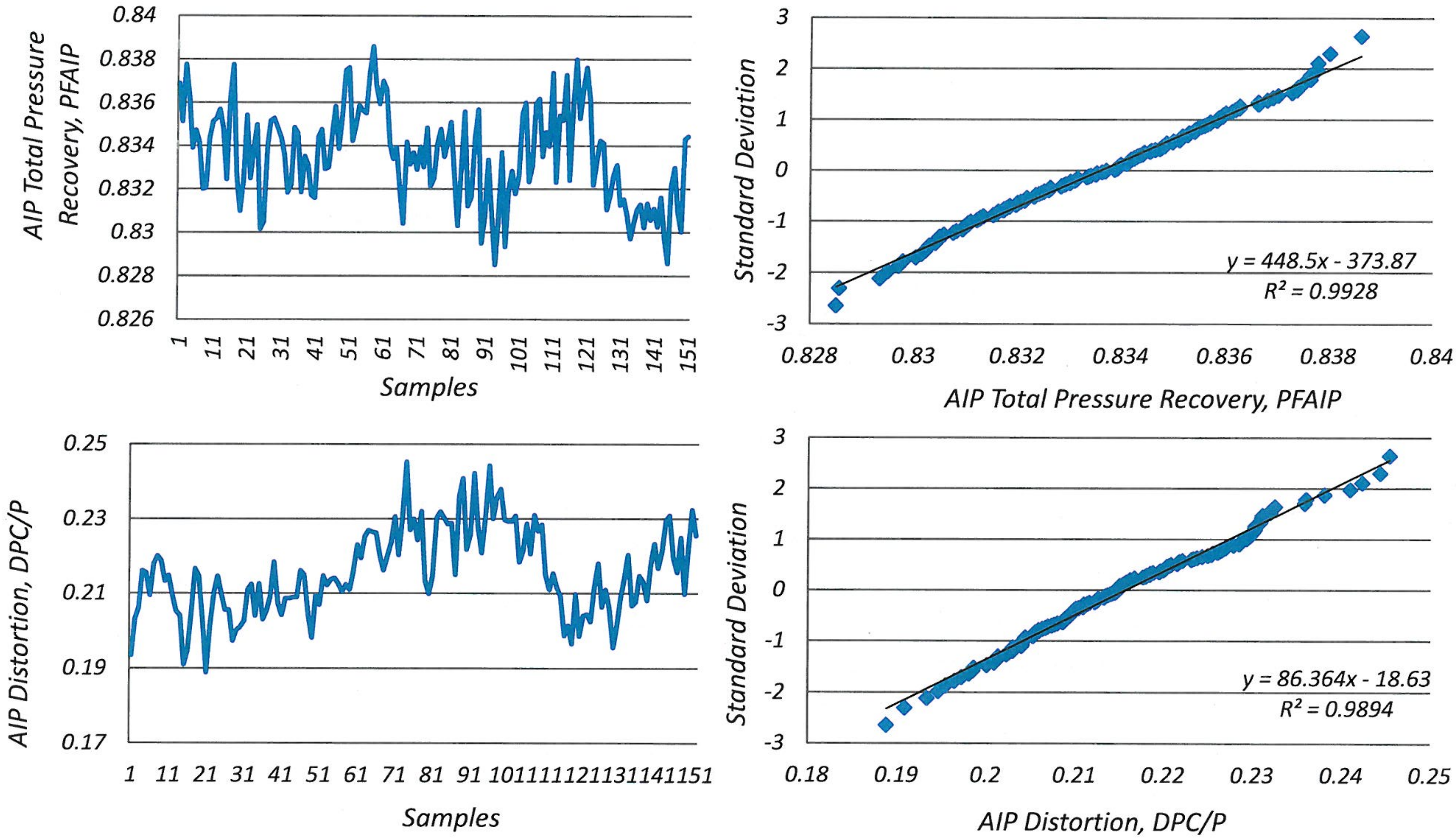


*3D Steady RANS Analysis*



*3D Unsteady DES Analysis*

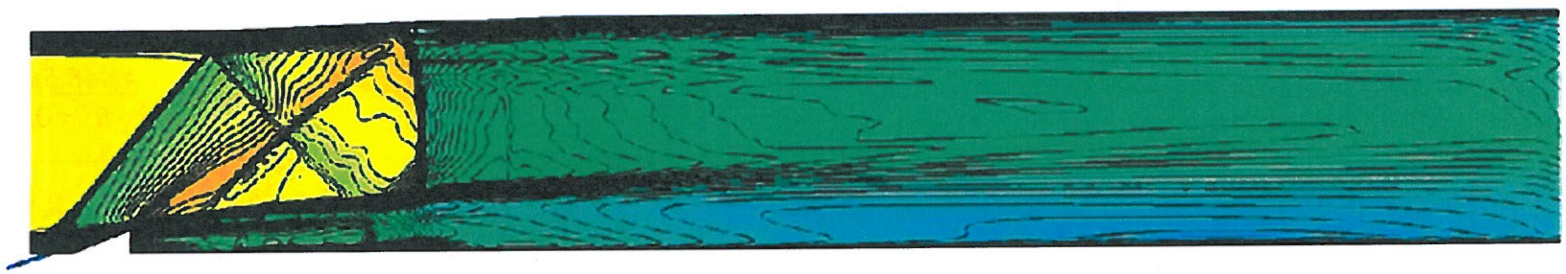
# Config. GRC401 HyFM Actuator Flow Control Stochastic Properties




Measured Observations

Normal Scores Diagram

# Config. GRC402 HyFM Actuator Flow Control Geom.
# Streamwise Mach Number Contours
# Superitical Operation
# $m_{bld}/m_0 = 5.0\%$



3D Steady RANS Analysis

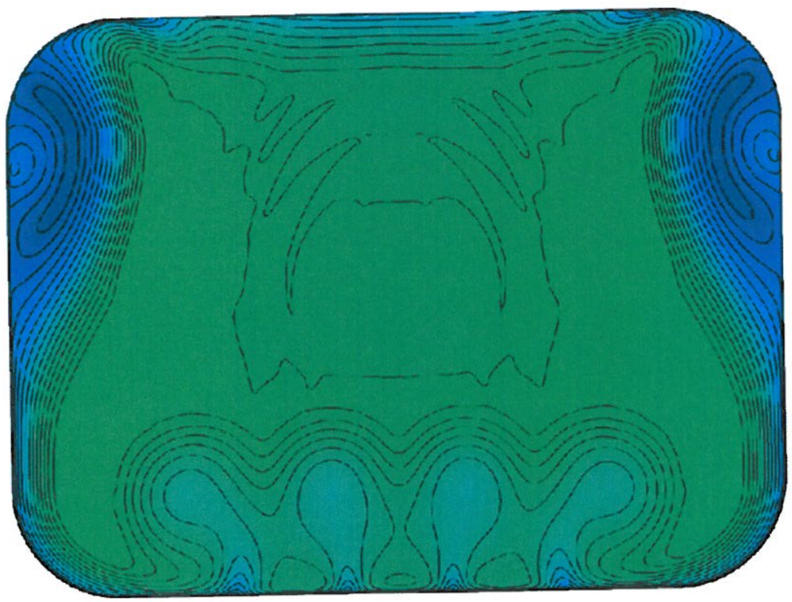
3D Unsteady DES Analysis

# Config. GRC402 HyFM Actuator Flow Control Geom.
## Streamwise Mach Number Contours
## Supercritical Operation
## $m_{bld}/m_0 = 5.0\%$

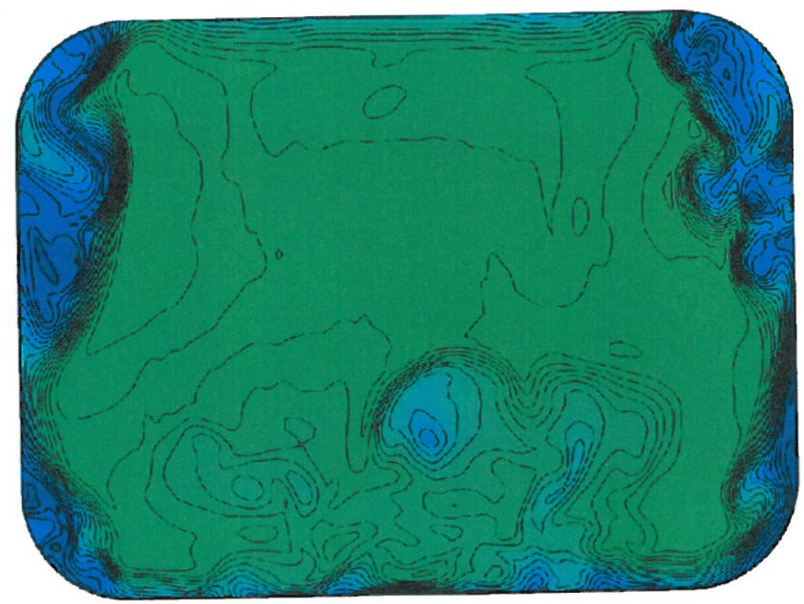
3D Steady RANS Analysis

3D Unsteady DES Analysis

# Config. GRC402 HyFM Actuator Flow Control Geom.
# AIP Mach Number Contours
# Supercritical Operation
# $m_{bld}/m_0 = 5.0\%$

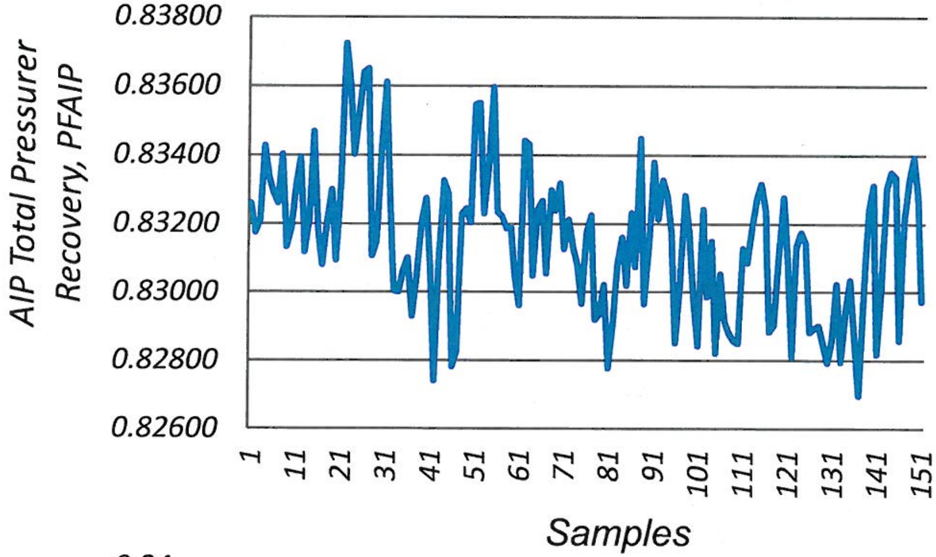


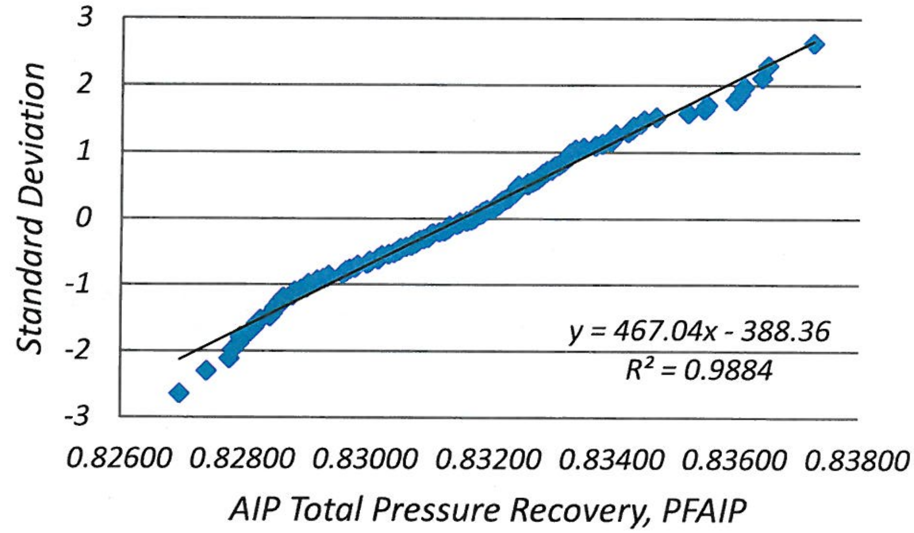
*3D Steady RANS Analysis*

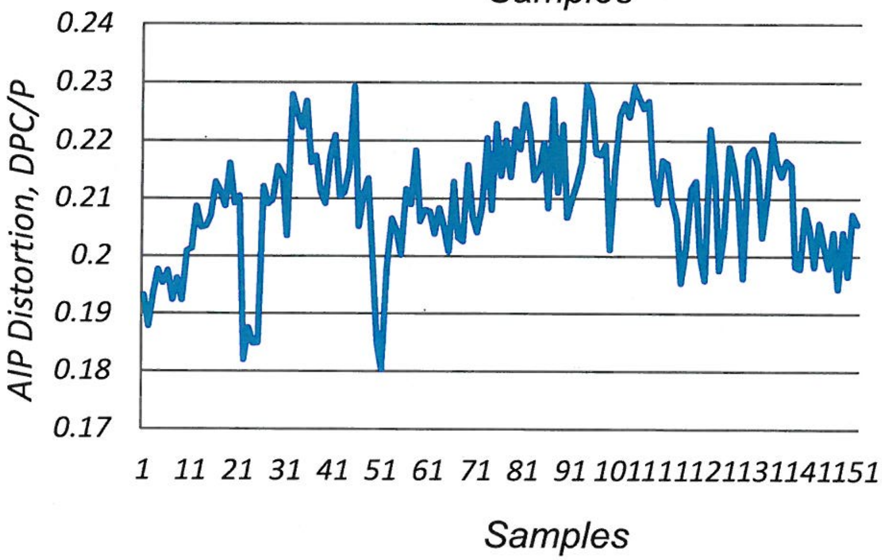


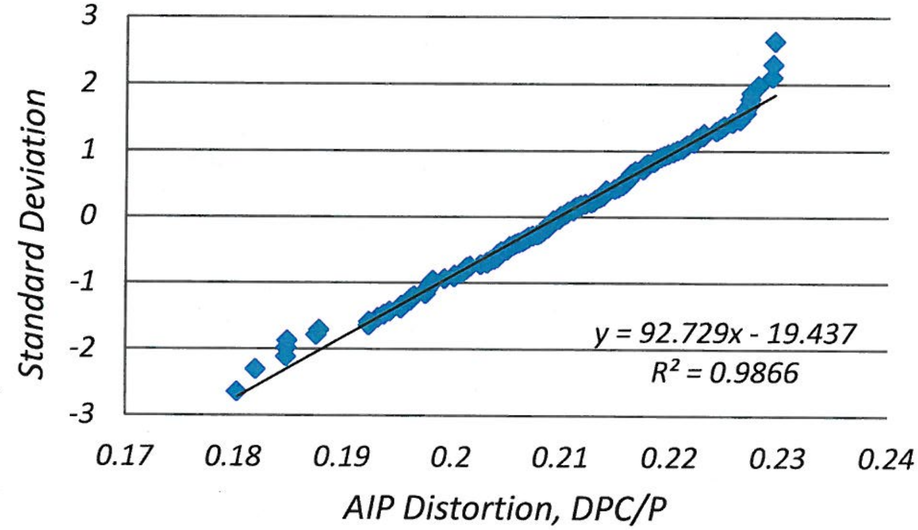
*3D Unsteady DES Analysis*

# Config. GRC402 HyFM Actuator Flow Control Stochastic Properties



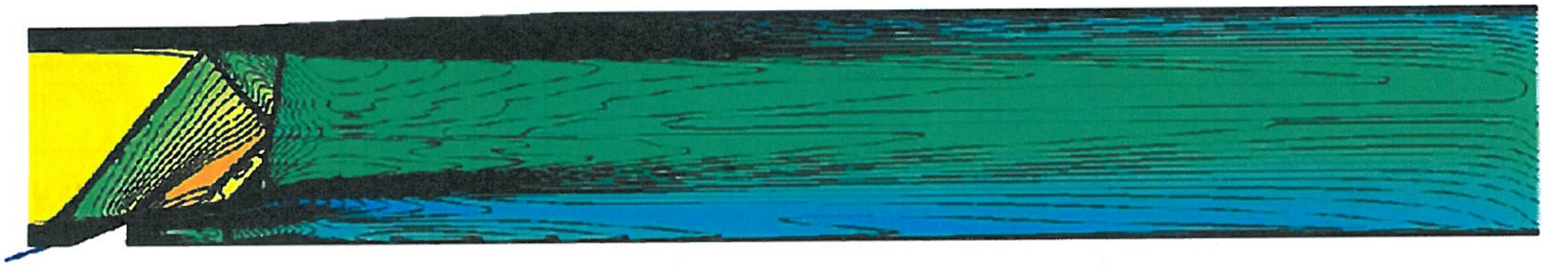




Measured Observations

Normal Scores Diagram

# Config. GRC403 HyFM Actuator Flow Control Geom.
# Streamwise Mach Number Contours
# Subcritical Operation
# $m_{bld}/m_0 = 0.0\%$

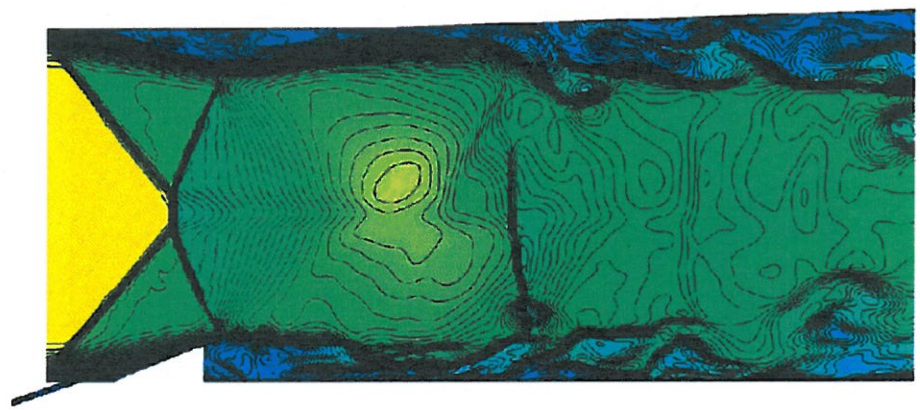


*3D Steady RANS Analysis*

*3D Unsteady DES Analysis*

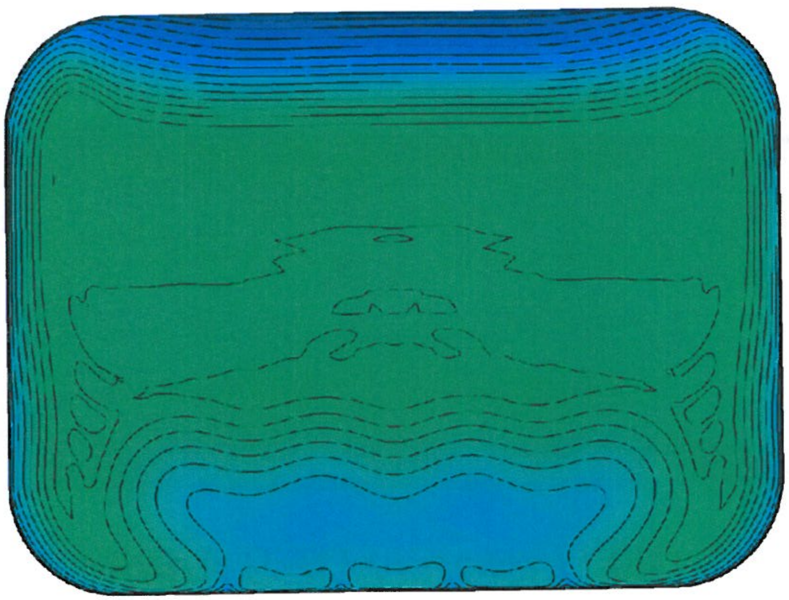
# Config. GRC403 HyFM Actuator Flow Control Geom.
# Streamwise Mach Number Contours
# Supercritical Operation
# $m_{bld}/m_0 = 0.0\%$

3D Steady RANS Analysis

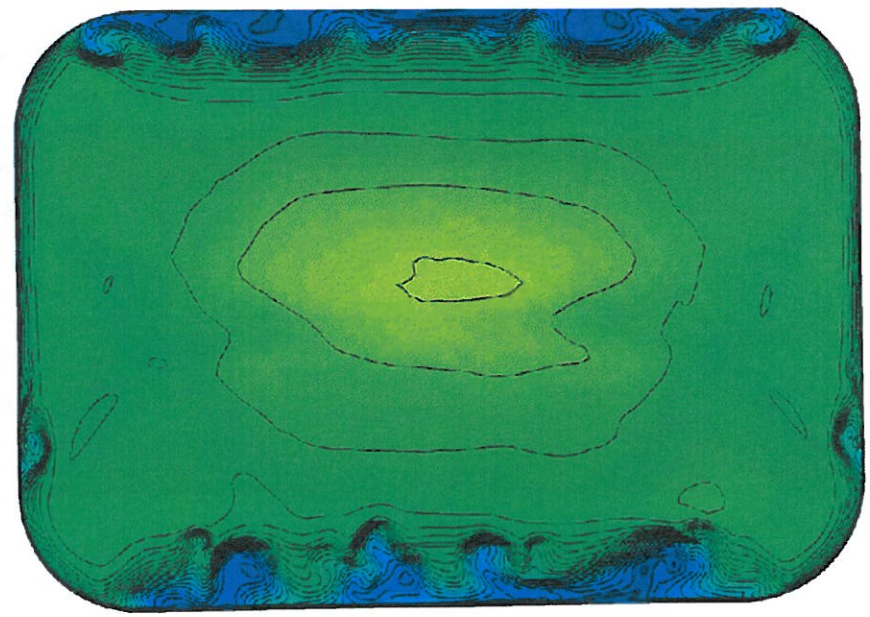


3D Unsteady DES Analysis

# Config. GRC403 HyFM Actuator Flow Control Geom.
# AIP Mach Number Contours
# Supercritical Operation
# $m_{bld}/m_0 = 0.0\%$

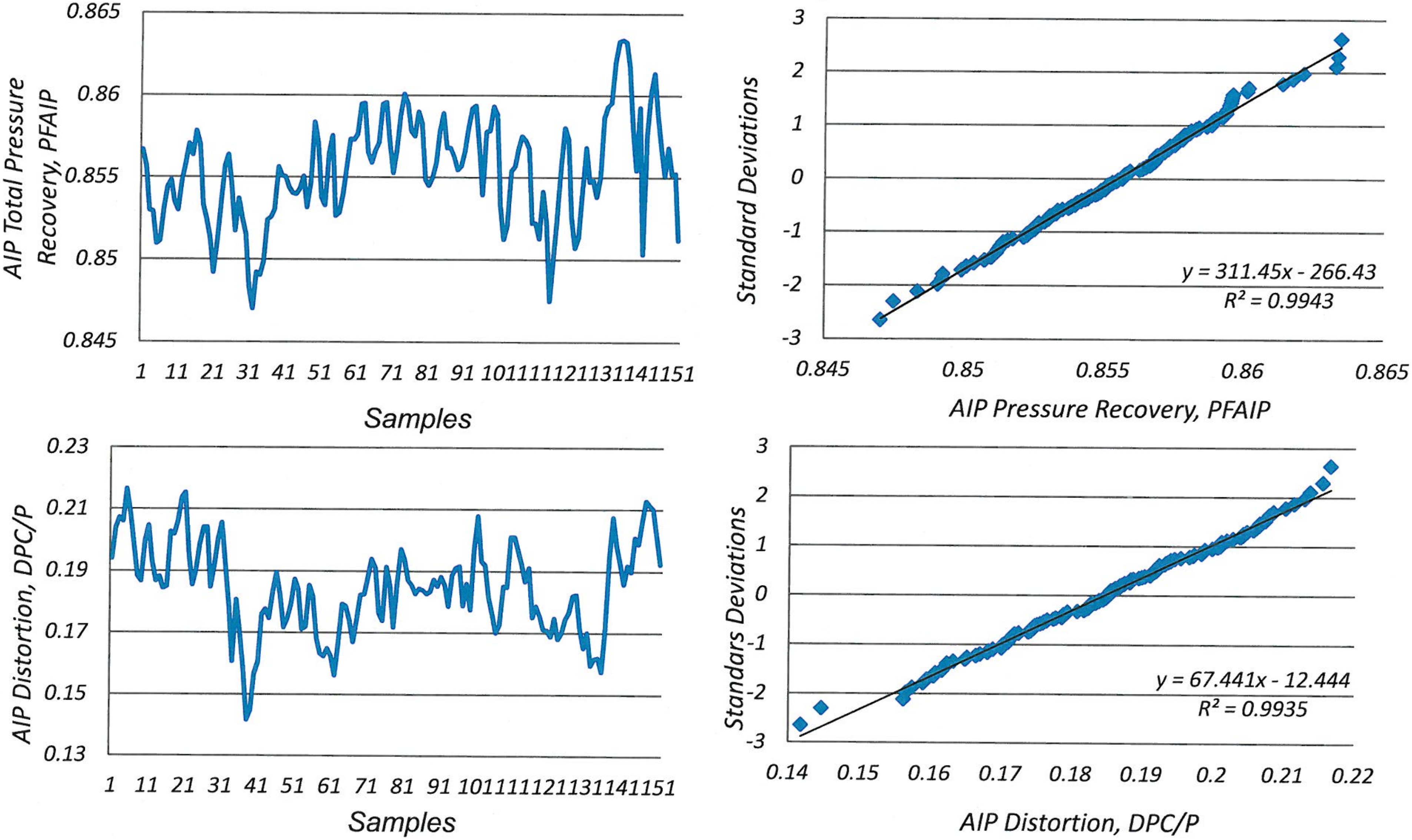


3D Steady RANS Analysis



3D Unsteady DES Analysis

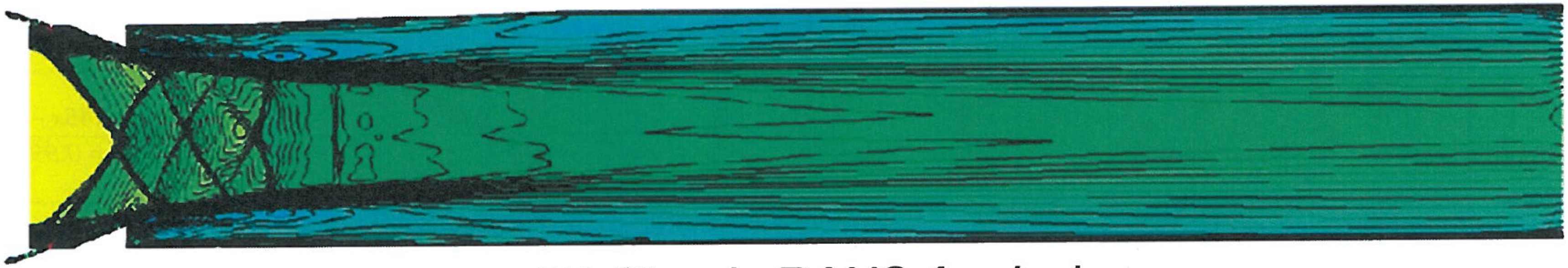
# Config. GRC403 HyFM Actuator Flow Control Stochastic Properties




Measured Observations

Normal Scores Diagram

## Config. GRC601 HyFM Actuator Flow Control Geom.
## Streamwise Mach Number Contours
## $m_{bld}/m_0 = 0.0\%$



3D Steady RANS Analysis
(Critical Operation)

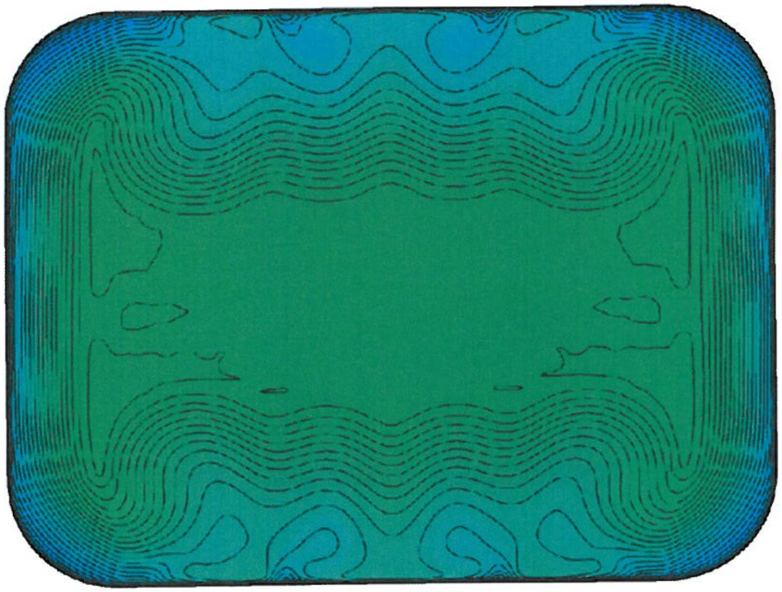
3D Unsteady DES Analysis
(Subcritical Operation)

# Config. GRC601 HyFM Actuator Flow Control Geom.
# Streamwise Mach Number Contours
# $m_{bld}/m_0 = 0.0\%$

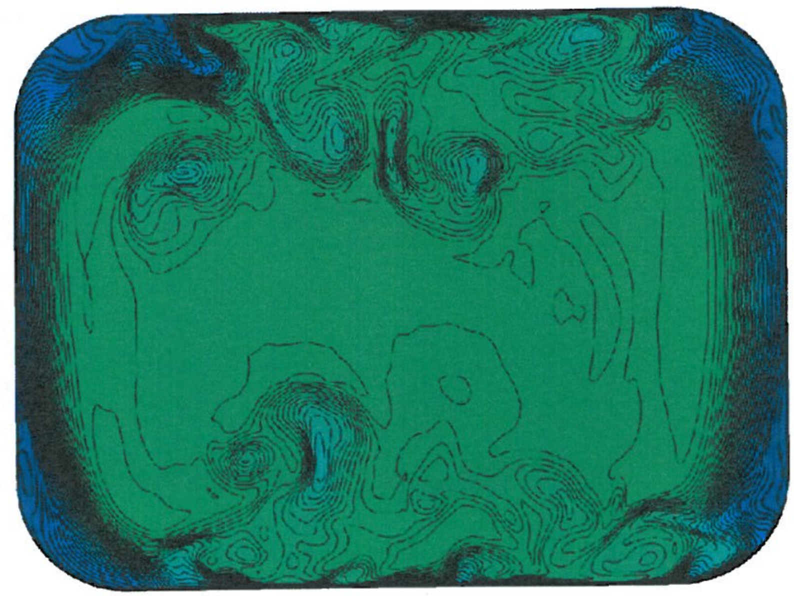
*3D Steady RANS Analysis*
*(Critical Operation)*

*3D Unsteady DES Analysis*
*(Subcritical Operation)*

# Config. GRC601 HyFM Actuator Flow Control Geom.
# AIP Mach Number Contours
# $m_{bld}/m_0 = 0.0\%$

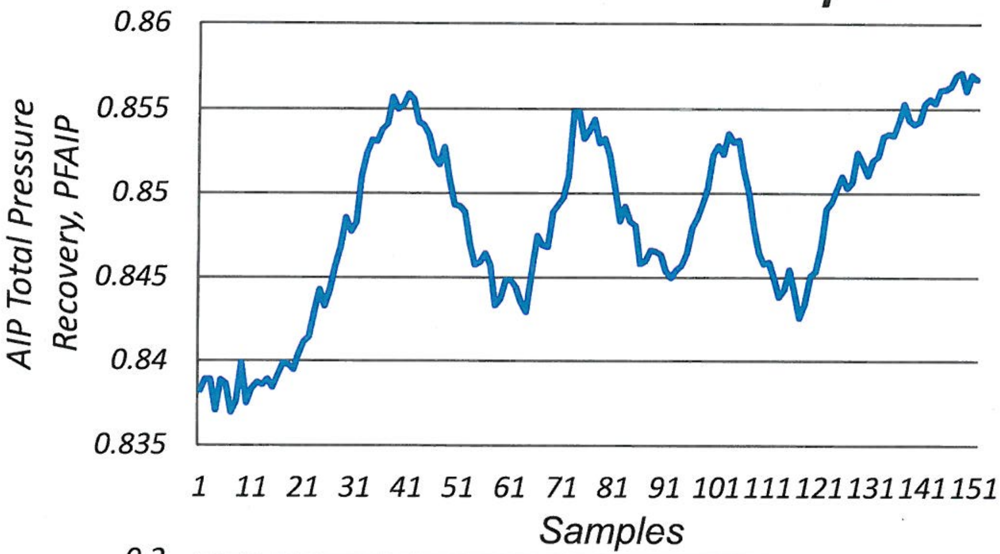


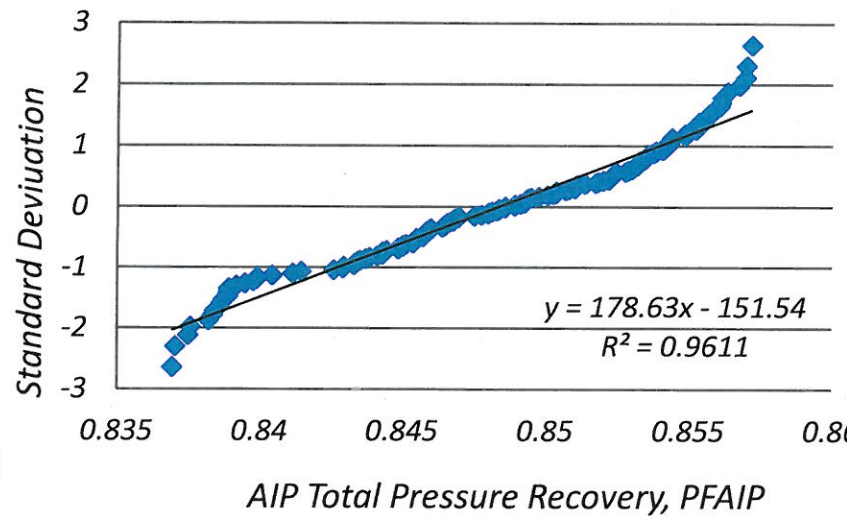
*3D Steady RANS Analysis*
*(Critical Operation)*

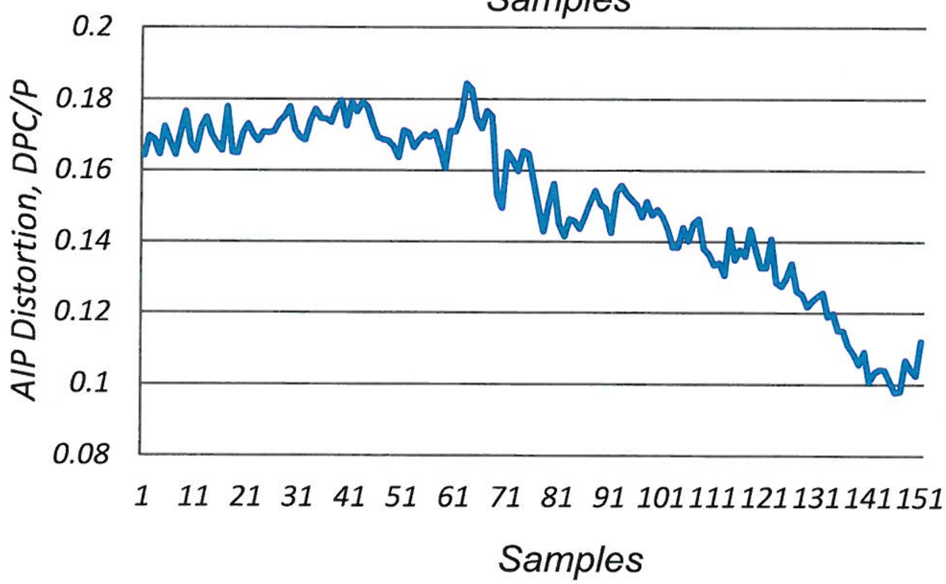


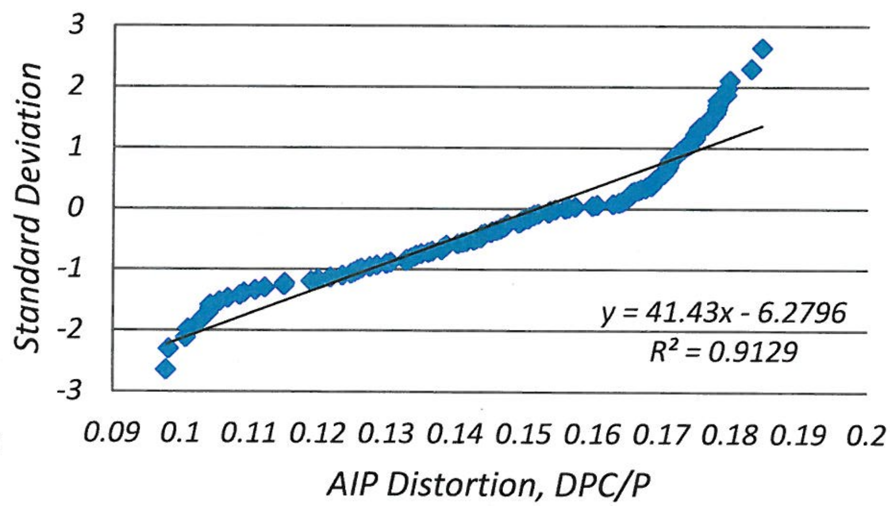
*3D Unsteady DES Analysis*
*(Subcritical Operation)*

# Config. GRC601 HyFM Actuator Geometry Stochastic Properties of Flow Control




Measured Observations

Normal Scores Diagram

# *Flow Control for Normal SWBL Corner Interactions General Observations to Date*

*A statistical comparison between 3D RANS steady and DES unsteady CFD solutions made to separate the various random (precision) and systematic (biasing) errors that are introduced into the estimates of the ARP1420 response parameters PFAIP, DPC/P results in the following conclusions:*

- *The primary flow variables, in particularly, the average Mach number (MAIP) and total pressure recovery (PFAIP) are statistically not different .*

- *Under conditions of large flow separations, the AIP DPC/P distortion determined from the RANS analysis is biased low compared to the mean average DES solution.*

- *As the flow becomes more attached, both RANS and DES solutions tend to the same DPC/P value.*

# Flow Control for Normal SWBL Corner Interactions References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