



**Flight validation of cruise efficient, low noise, Extreme short takeoff and landing (CESTOL) and circulation control (CC) for drag reduction enabling technologies**

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## ***Vision-*** CESTOL Airliners to reduce airport congestion

NASA Aeronautics Research Institute

“The FAA estimates that increasing congestion in the air transportation system of the United States, if unaddressed, would cost the American economy \$22 billion annually in lost economic activity by 2022” FAA Fact sheet

The FAA Next Generation (NextGen) Air Transportation System Project is transforming the current Air Traffic Control System to address this issue. Nextgen, in addition to modernizing current guidance, arrival and departure technologies and procedures, is opening the door for new aircraft types like CESTOL that will significantly contribute to reducing air traffic congestion, flight delays and airport noise.

The unique capabilities of CESTOL Aircraft accomplish this in three ways:

- By using underutilized shorter runways at larger airports
- By using smaller underused airports in metropolitan areas
- STOL flight trajectory keeps offending aircraft noise within airport boundary



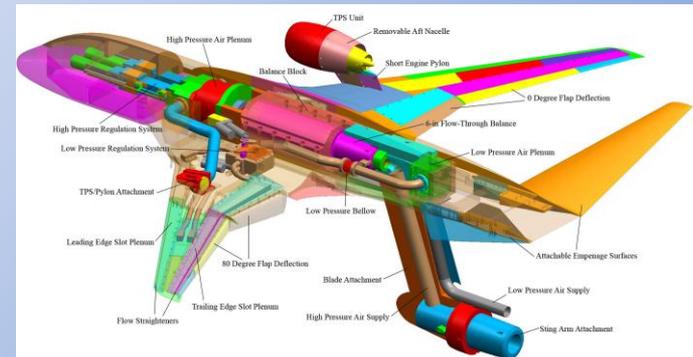


# Background- CESTOL Wind Tunnel Testing

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## Advanced Model for Extreme Lift and Improved Aeroacoustics (AMELIA)

- 1/11 Scale wind tunnel model of a future 100 passenger CESTOL aircraft
- Joint collaboration between NASA ARC and CalPoly San Luis Obispo
- Over 290 data run were made in the National Full-Scale Aerodynamics Complex (NFAC)



- Tests show improvements to lift performance with circulation control
- Tests also showed importance of leading edge blowing for stall prevention



# Background- Flight Test the next step

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- Flight Test has proven crucial from moving new technology and ideas from the lab to use in the real world
  - Focus on overall aircraft, not components (wings, engines, controls, etc.)
  - Provides integration and performance evaluation of new technology with conventional aircraft systems
  - Provides insight into operational challenges; flight control law design, aircraft handling qualities, transients and unsteady flow effects, stall and upset characteristics
- Despite proven benefits, few new technologies go beyond the lab or wind tunnel tests to full or sub scale flight test and to eventual use in the real world due to:
  - High costs in developing and testing a new dedicated X-plane
  - High costs and difficulties modifying existing aircraft as aerodynamics and circulation control test beds
  - Time to build or modify a test aircraft requires early program funding and static research priorities





# Innovation: A highly reconfigurable test bed aircraft to test CESTOL and other circulation control (CC) technologies

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## Prototype Test Evaluation Research Aircraft (PTERA)



**PTERA Base Line (BL)**

- 10% Scale B-737 Like aircraft
- 11 ft wing span, 10 ft length, 200 lbs wt
- Flight tested Spring 2013
- Additional testing Summer 2014
- Flight test data includes complete Baseline performance data and aero coefficients available to researchers
- Delivery of PTERABL to NASA in Fall 2014 under NASA SBIR Program



**PTERA Combined Circulation Control (C3)**

- Modification of PTERABL under ARMD Seedling fund to add and test CESTOL circulation control technologies
  - Dual radius CC trailing edge flap
  - Leading edge flow control
  - Over-the-wing powered lift engine
- Flight testing in Phase 2 will allow direct performance comparisons with PTERABL as well as maturing CESTOL/CC technologies



# Phase 1 Technical Approach

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- Remove PTERA BL equipment from vehicle
- Install CESTOL/CC hardware to convert PTERA BL to PTERA C3
- Perform functional testing of all PTERA C3 hardware
- Develop releasable PTERA Simulation using NASA DFRC Core Simulation Architecture and standard tools.
- Develop aero data tables for PTERA BL and PTERA C3 for use in simulator from previous wind tunnel and flight data
- Perform ground testing of PTERA C3 at Georgia Tech Research Institute to measure wing exit pressures at several points on the wing trailing edge at different throttle and plenum gate setting.
- Add ground test data to PTERA Simulations for use in controller development in Phase 2
- Other preparations required for flight test in Phase 2.



# Impact of Innovation

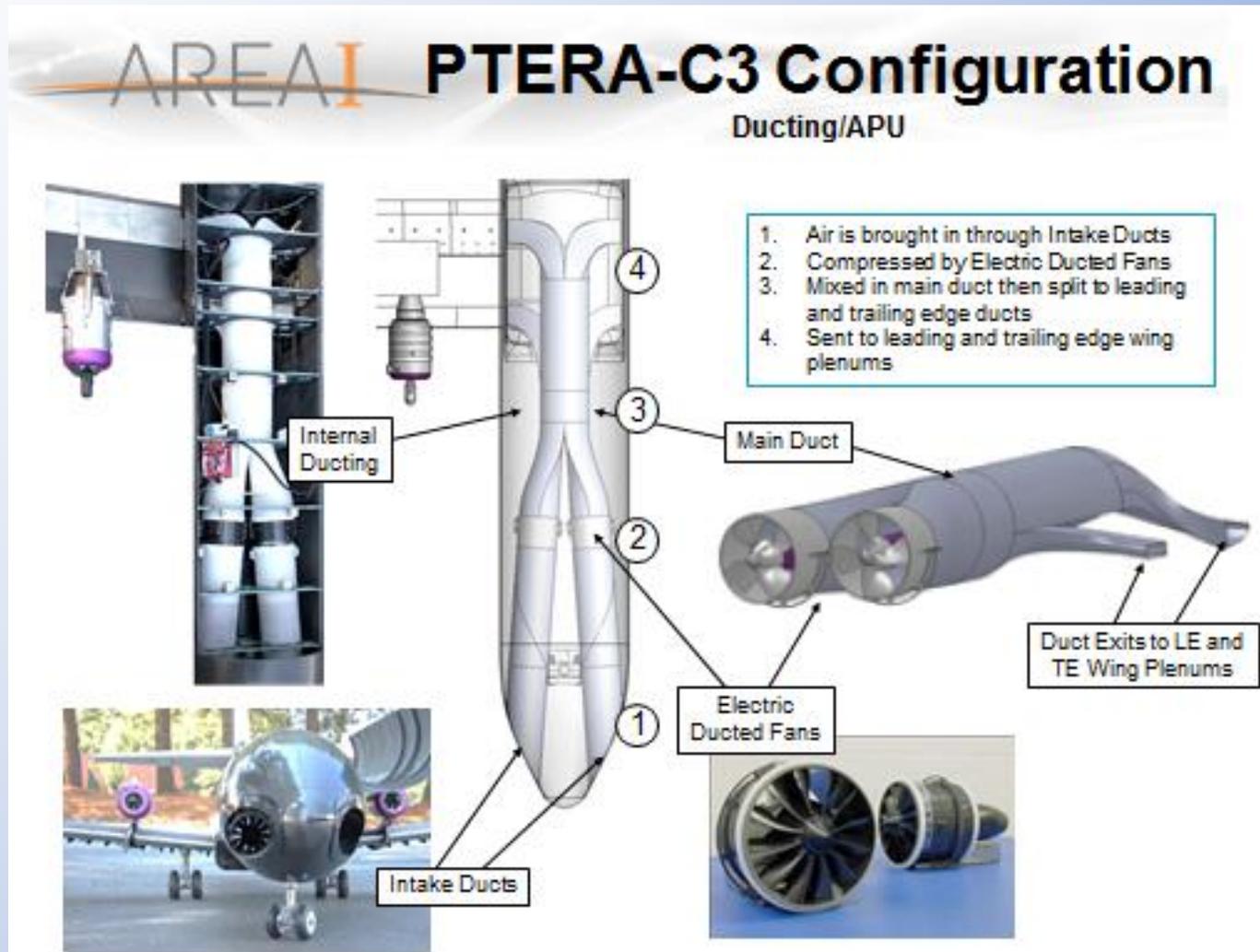
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- This innovation will increase TRL of CESTOL/CC technology thru early flight test at a cost much lower than other flight test aircraft.
- Performance of CESTOL/CC technologies can be realistically determined by direct comparison to a base line aircraft.
- This innovation will provide test data, simulations and development of a highly capable, highly reconfigurable flight test vehicle for use by researchers in the Circulation control community.



# System Layout

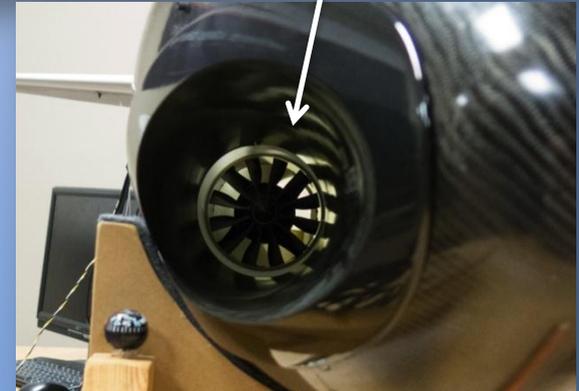
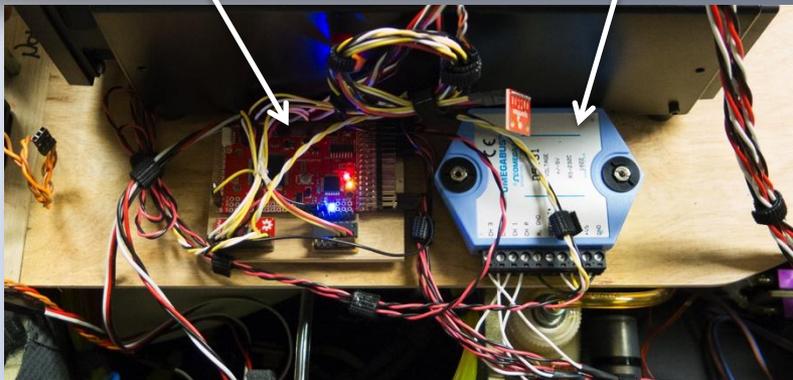
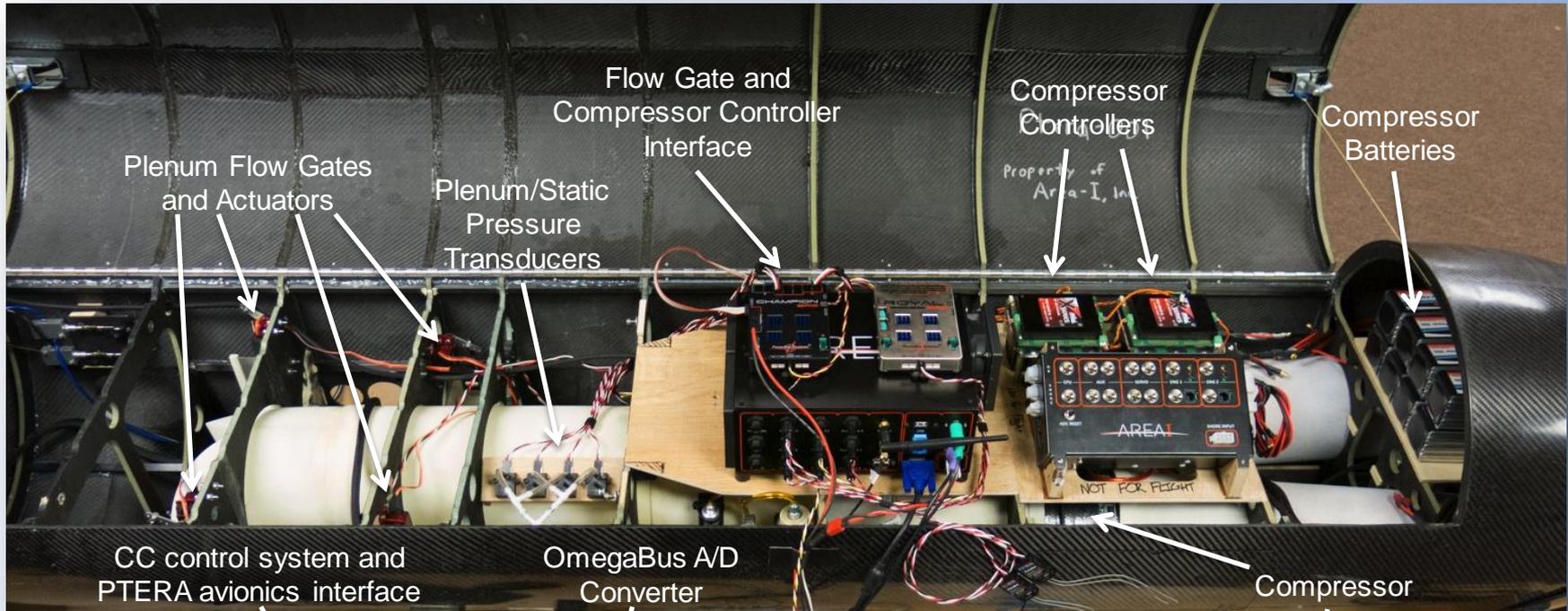
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# PTERA-BL to PTERA-C3 Conversion

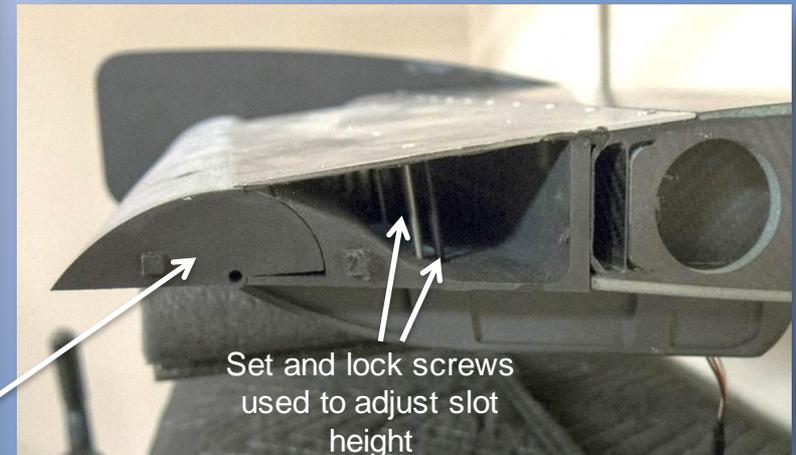
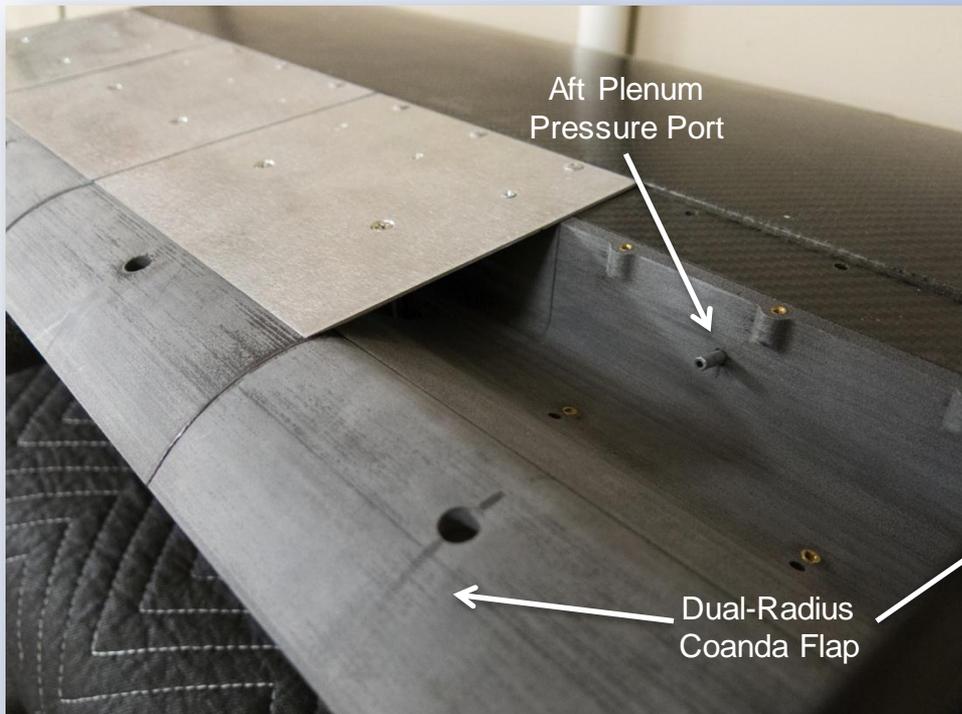
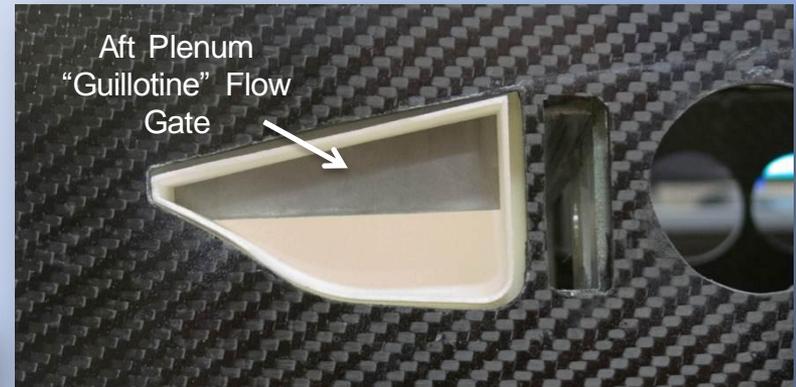
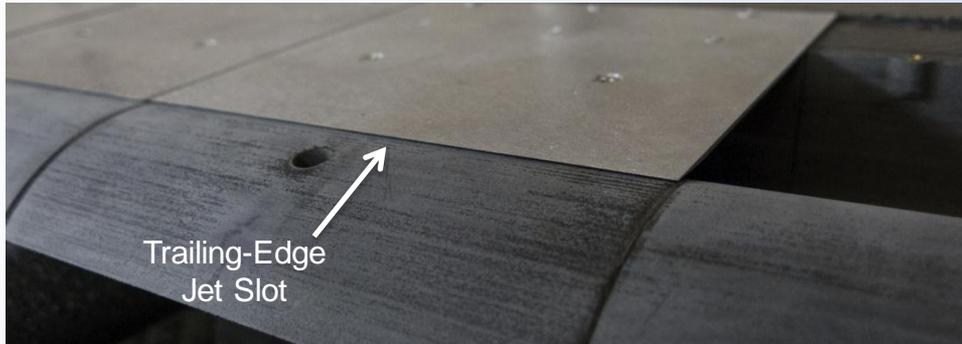
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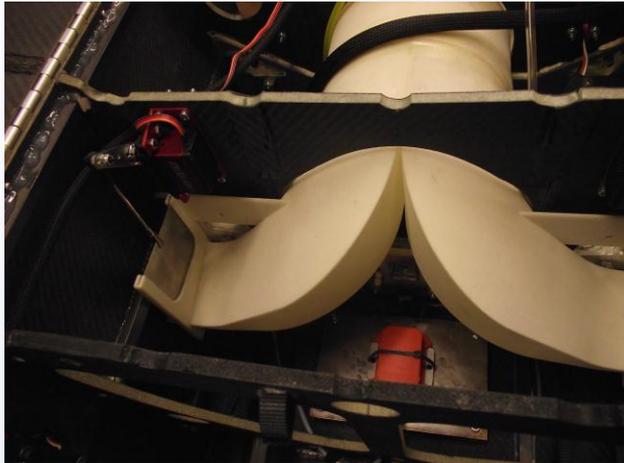
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# Test Setup

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- Compressor throttle and plenum gate openings were commanded from the right computer. Other computers were used for data collection.
- Miniature pitot tube was used to gather pressures at several wing exit locations.
- Data was recorded on both wings



# Movie: PTERA C-3 Data Collection

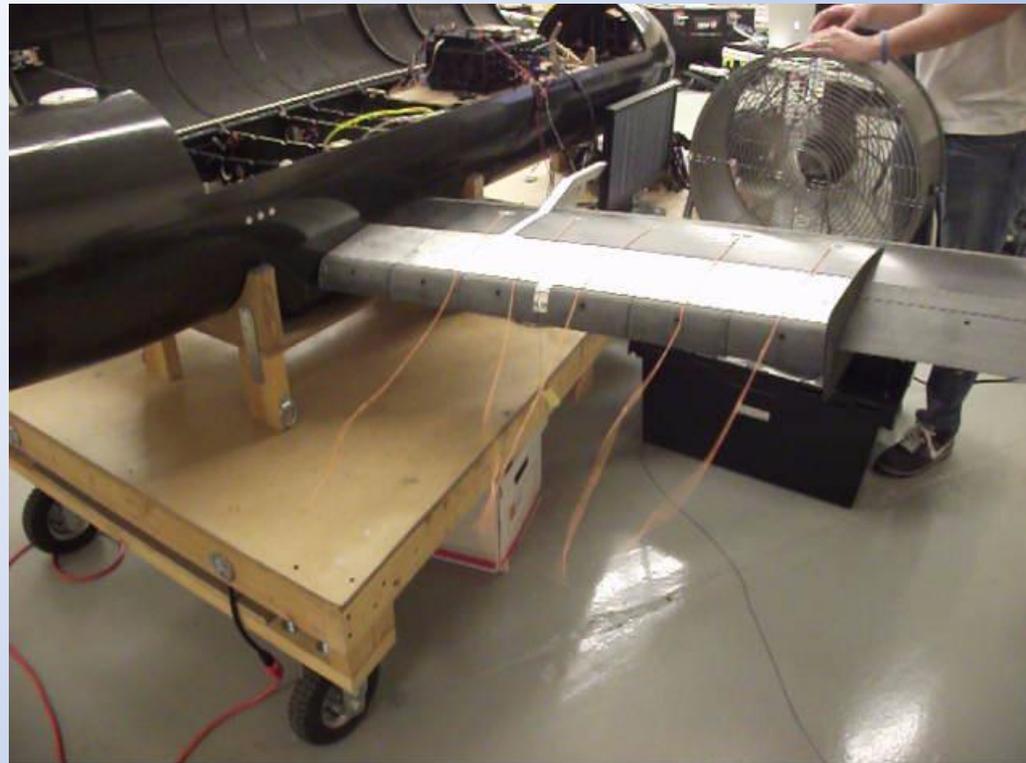
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# Movie: PTERA C3 Flow Visualization

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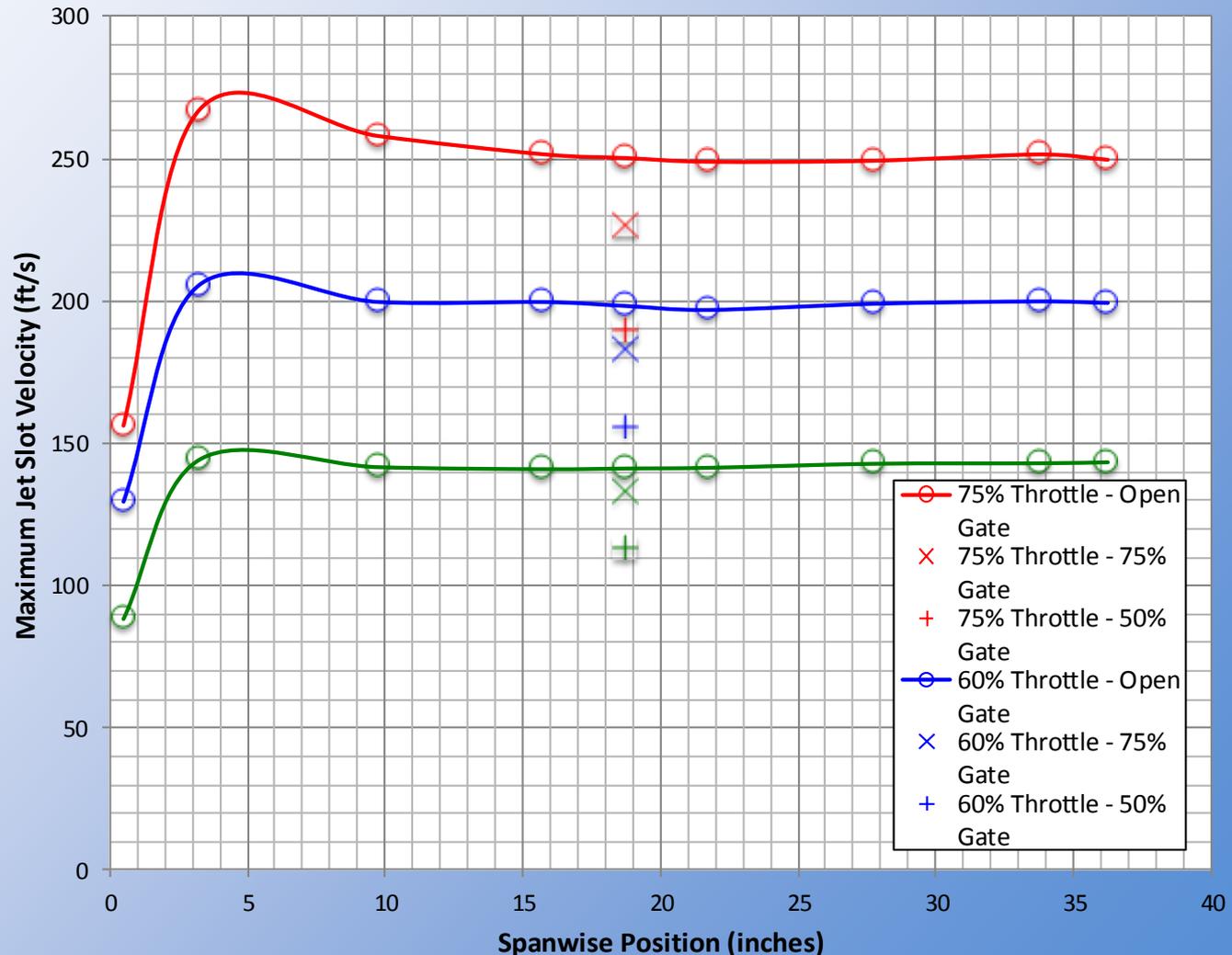




# Preliminary Test Results

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## Left-Wing Jet Slot Velocity Measurements



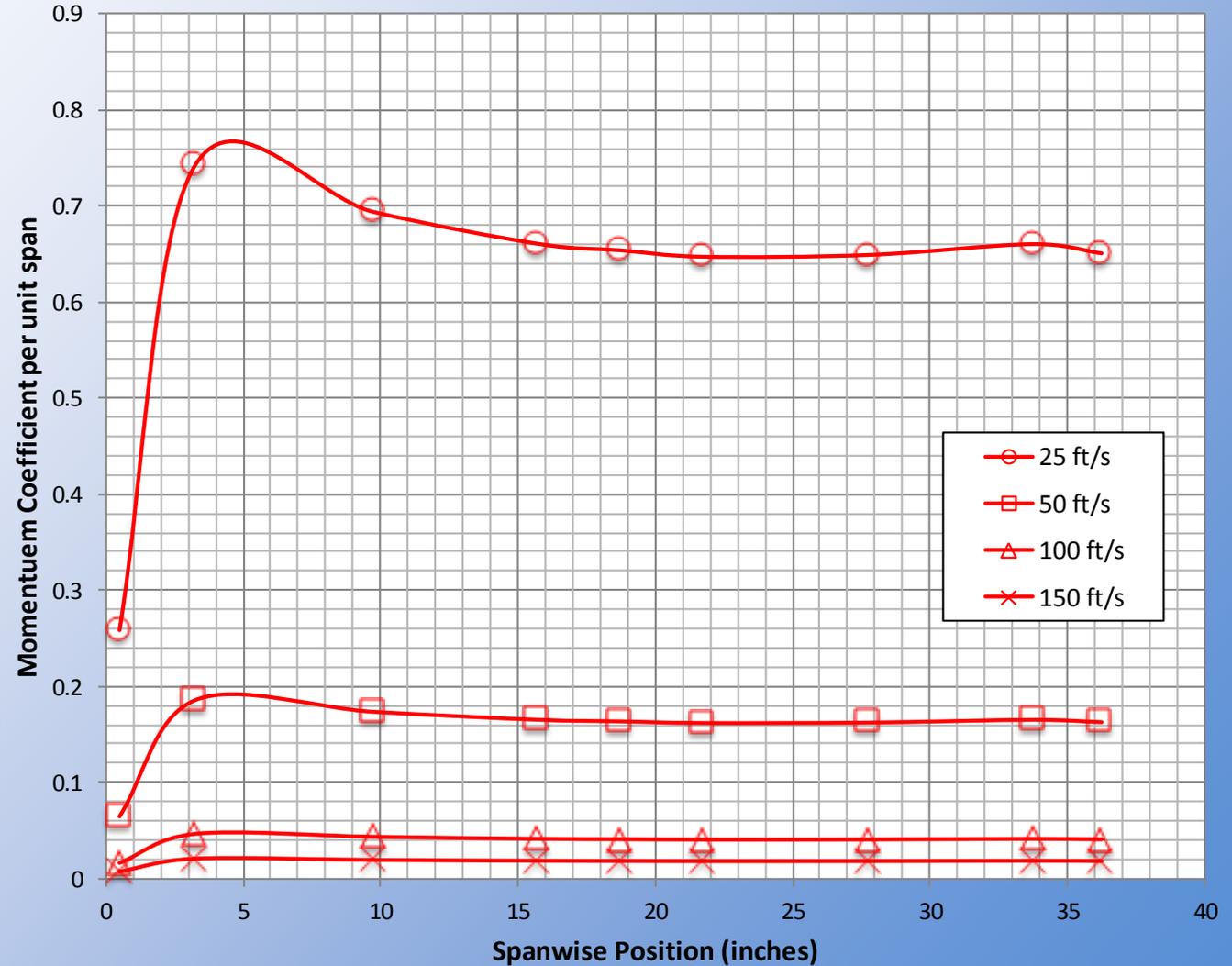
- Maximum jet slot velocities were measured along the span at various compressor throttle settings with open flow gates
- Two mid-span (15.75" and 21.75") measurements at various throttle and gate settings were also taken (averaged values at 18.75" are shown in chart)
- The velocity measurements will be used with corresponding internal plenum pressure measurements to develop flow system control algorithms



# Preliminary Test Results

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## Momentum Coefficient vs. Airspeed (75% Throttle)



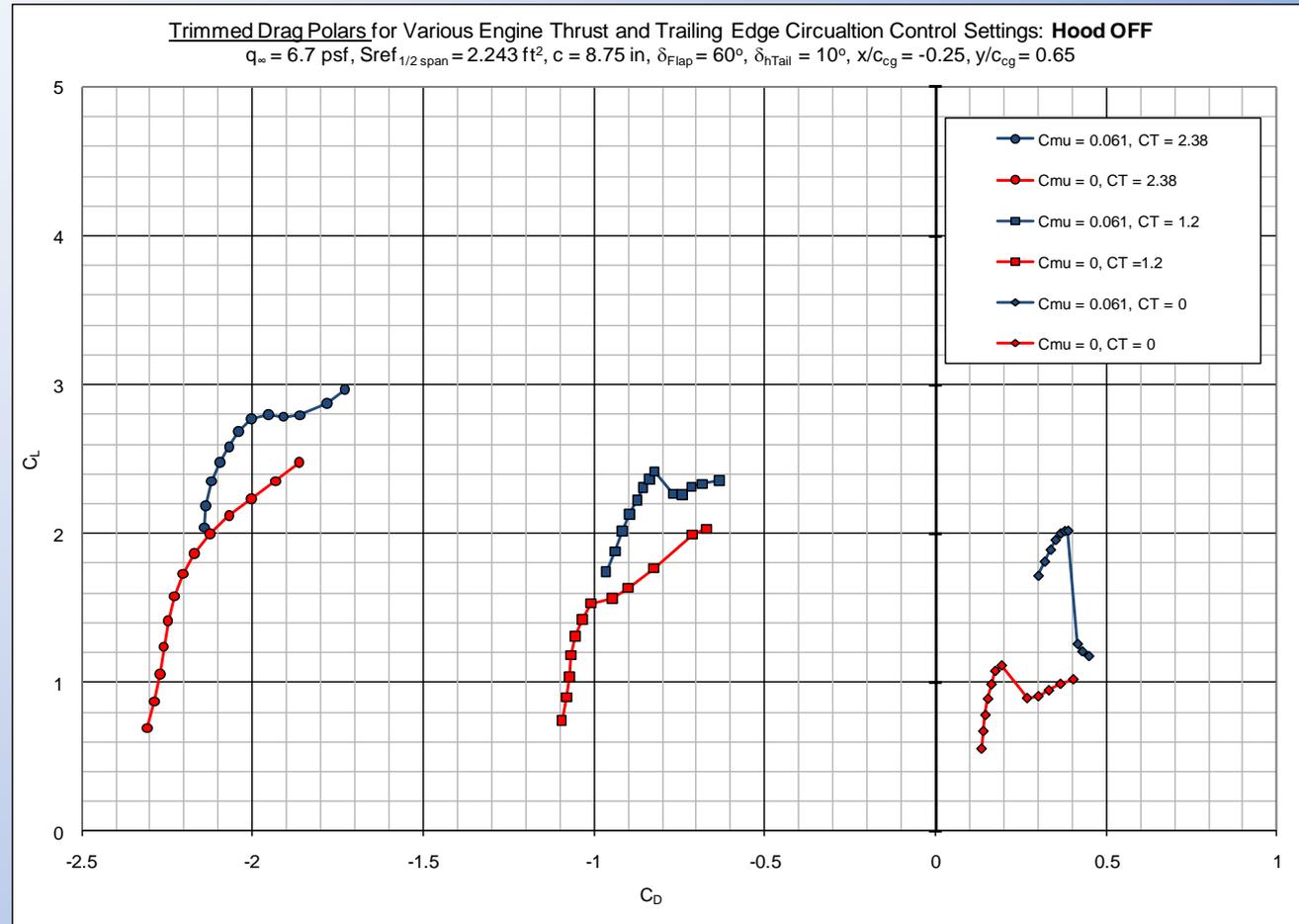
- The momentum coefficient varies with airspeed:  
$$C_{\mu} = \dot{m}V_j/qS$$
- Note that momentum coefficients presented here are based on the maximum slot velocity, and assume a fully turbulent flow profile.
- Circulation control system was designed to provide a total  $C_{\mu}$  of 0.061 at an airspeed of 44 ft/s. Even at reduced throttle setting, the system is easily able to achieve this (see following slide for wind tunnel results)



# Preliminary Test Results

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- PTERA-C3 wind tunnel data was collected under Phase II SBIR Contract #: NNX08CA44P at GTRI's model test facility
- Shows lift coefficient increases of over 0.8 for a total  $C_{\mu}$  of 0.061 at an airspeed of 44 ft/s.





# Test Data and Flight Simulation

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- All ground test data as well as future flight test data will be available to interested researchers
- Test data will be added to the proprietary Area-I SimX flight simulator during Phase 2
- As part of the Phase 1 effort, a releasable simulation of PTERA C3 was developed utilizing the NASA DFRC Core simulation structure. Ground test data will also be added to this simulation.
- The NASA DFRC simulation also includes data for the baseline PTERA aircraft that can be used for comparison with PTERA C3

The screenshot shows the PTERA flight simulation software interface. The main window displays a cockpit view with various instruments and controls. The 'PTERA Control Panel' window is open, showing flight parameters such as Mach (0.98), AOA (10.9), and Beta (-9.0). The 'PTERA Main Window' displays a log of engine data and engine outputs.

Clock	Time	Type	Message	Source
12:31:10.6	0.000	ENG	1	USER
12:31:16.0	0.000	ENG	2	USER
12:32:14.8	0.000	TRIM	pa.enable=0	USER
12:32:30.3	0.000	CALC	e.pla1=0	GUI
12:32:34.5	0.000	COMMAND	OP	USER
12:32:45.9	11.380	COMMAND	PST	USER
12:33:05.5	0.000	CALC	e.pla2=21.9615	GUI
12:33:09.2	0.000	COMMAND	OP	USER
12:33:12.5	3.300	COMMAND	PST	USER

table Eng2	---	Engine 2 - Right	---
table Eng2.in	---	Engine Inputs	---
int32	id		Engine number
string	file_name		Table lookup file name
double	y_pos	1.70250	ft Y location of engine front
double	z_pos	0.78830	ft Z location of engine front
double	theta	0.00000	deg Pitch angle between thrust
double	beta	0.00000	deg Yaw angle between thrust
double	plaz	21.9615	% Power lever angle for eng
table Eng2.tab	---	Engine table lookup results	---
double	thrust	10.3182	lbf Engine output thrust
double	fflow	27.0056	lbm/hr Fuel flow rate
double	ep	0.00000	Engine pressure ratio
double	tsfc	0.00000	lbm/lbf-hr Thrust specific fuel cons
double	n1	56259.9	rpm Rotational speed of fan
double	n2	0.00000	rpm Rotational speed of comp
double	pres2	0.00000	psia Inlet total pressure
double	pres9	0.00000	psia Nozzle total pressure
double	temp2	0.00000	R Turbine inlet total temp
table Eng2.out	---	Engine outputs	---
double	fx	10.3182	lbf X body axis engine force
double	fy	0.00000	lbf Y body axis engine force
double	fz	0.00000	lbf Z body axis engine force
double	mx	0.00000	ft-lbs Engine moment about X bod
double	my	-7.38939	ft-lbs Engine moment about Y bod
double	mz	-17.5668	ft-lbs Engine moment about Z bod



# Summary

- Circulation control system was integrated into PTERA C3 testbed in preparation for flight test
- Sensors were integrated and software developed to accurately control CC system.
- Bench tests of CC system were carried out to characterize the flow and overall system performance. These tests exceeded predicted performance and helped identify parameters that will be used in the development of CC system control algorithms, simulation models, and CC aircraft control algorithms
- A 6 DOF flight simulation of PTERA BL and PTERA C3 was developed for eventual release to CC researchers
- Began technical report on CC system, aircraft modifications and testing



# Distribution/Dissemination

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- Have had discussions and provided copies of the 6 month report to interested NASA personnel and industry representatives including:
  - Nhan Nguyen (Associate Technical Lead Aerodynamic Efficiency)
  - Robert Navaro (NASA DFRC Project Manager Aerosciences)
  - Gary Martin (NASA DFRC Project Manager Fixed Wing)
  - John Bosworth (NASA DFRC PI Fixed Wing)
  - Starr Ginn (NASA DFRC ARMD Chief Engineer)
  - James H. Mabe (Associate Tech Fellow Boeing Research and Technology)
- ARMD Seedling Fund Kickoff meeting at NASA Ames to discuss research effort and tie in to related projects such as AMELIA.
- Presented at the 2013 International Powered Lift Conference in Los Angeles California
- AIAA Paper on Phase 1 work to presented at a future AIAA Circulation Control or Flight Controls Conference



# Next Steps

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- Phase II Proposal with expertise from NASA, Georgia Tech Research Institute (GTRI), Boeing and Middle Georgia College will raise CESTOL TRL by:
  - Utilizing Phase 1 ground test data to refine simulator models
  - Use updated simulator to develop aircraft control laws and control circulation control system
  - Hardware in the loop tests and additional flight test preparation
  - Flight tests of CESTOL system including PID test points and analysis
- Further development of PTERA C3 aircraft to test other Circulation Control research technologies