Program status and future plans for Supersonic Propulsion integration research

Aerospace Vehicles Division

Integrity ★ Service ★ Excellence

Presented to the AFRL/NASA SBLI Technical Interchange Meeting, OAI, Cleveland

25 May 2016

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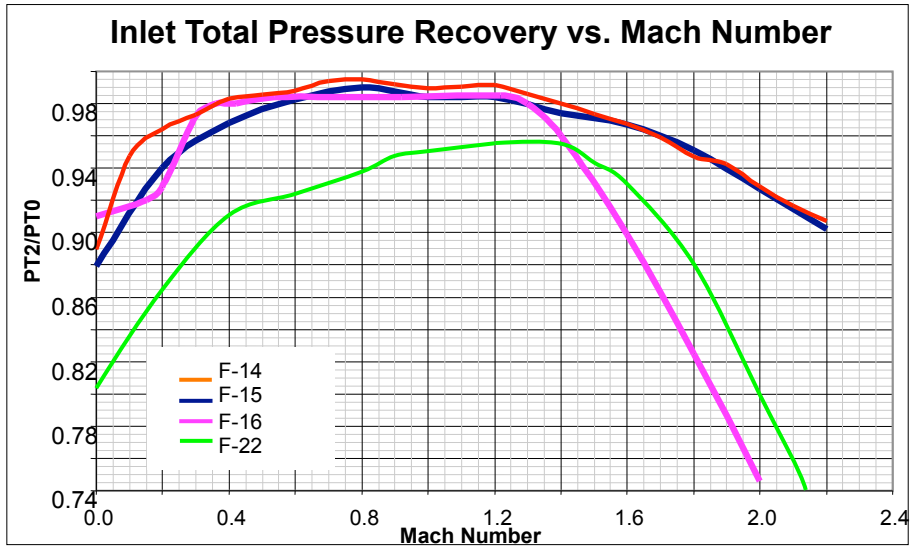
Briefing Content

- Motivation / Technologies for Future Air Dominance (FAD)
- Details of in-house efforts
  - SWBLI model CFD
  - ADAC facility design
- Plasma SBIR II results

Motivation / Technologies

Regain 4th gen. inlet aerodynamic performance while moving beyond 5th gen. survivability

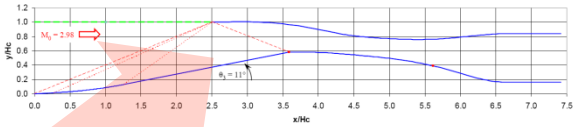


In-House Technology Development:

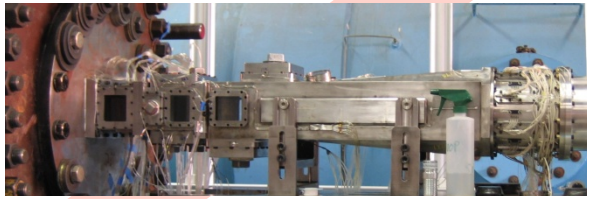
- **Bleed-less or low bleed shock wave boundary layer interaction flow control**
- **Subsonic diffuser flow control for aggressive diffusers downstream of normal shock**

Previous Research Plan

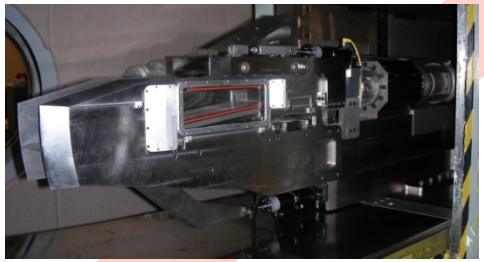
Range of Experiments for Inlet Flow Control and Analysis



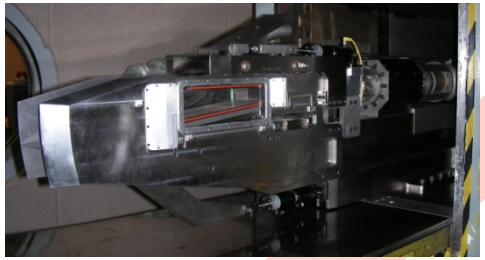
SOA mixed compression inlet system

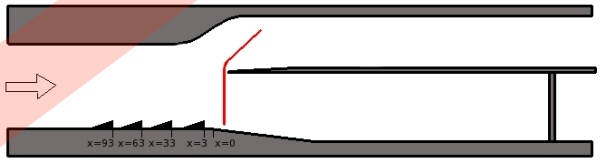


Correct flow throat to engine face, flight Re

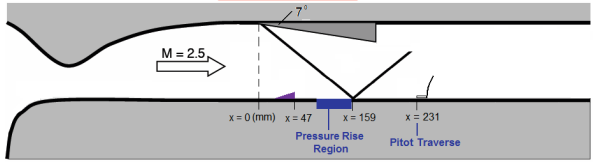


Multiple shock system with diffusion ,Generic mixed compression inlet system low Re (SWBLI Model)





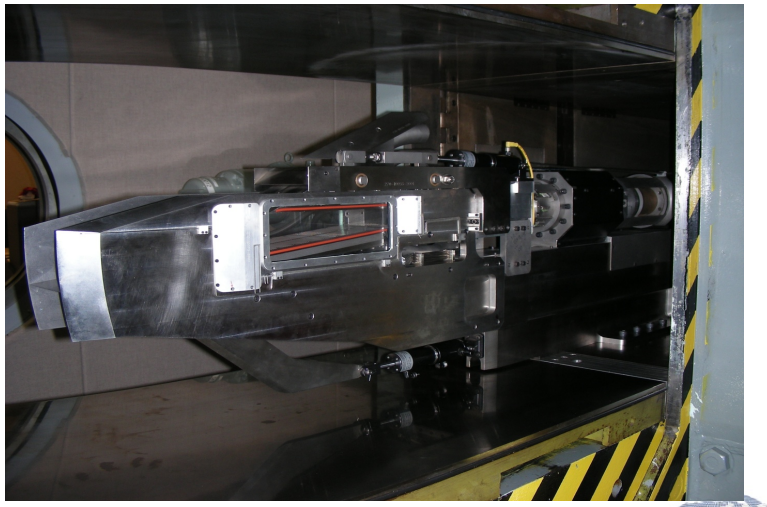
Single shock with diffusion



Single shock interaction

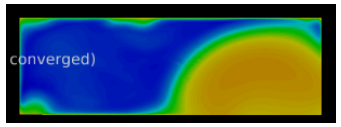
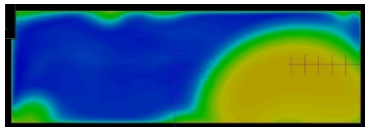
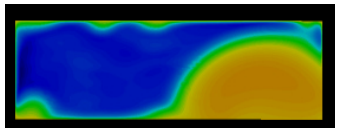
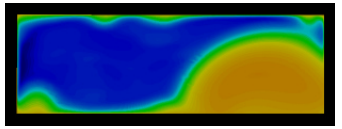
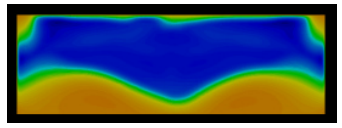
SWBLI CFD UPDATE

- **AFRL RQVI seeking CFD based design capability for inlet systems. Simulations of the SWBLI model being used to both gain understand of why the model was underperforming and ability to match test data.**
  - **Lockheed Martin conducted a series of simulations in the Winter of 2013**
  - **Analysis showed some potential reasons for low pressure recovery, LM installed the FALCON solver on the SPIRIT supercomputing network (USAF/AFRL)**
    - **AFRL has run multiple simulations varying the bleed plenum pressures and other boundary conditions**
  - **AFRL RQVI is also funding an RQVC contractor to simulate the SWBLI model using OVERFLOW**
    - **10+ months of work**
    - **Plausible results are finally being generated as of late April 2016**



Bleed Plenum Sensitivity

- **A trade study was conducted to test the bleed sensitivity of the SWBLI model flow field to plenum pressure.**
  - **Using the original grids generated by Lockheed Martin plenum pressure was varied around original simulation values, all were lower than tested values.**

	Did Not Converge	Did Not Converge					
Set/Domain	**80% Original (PSF)**	**90% Original (PSF)**	**95% Original (PSF)**	**Original input (PSF)**	**105% Original (PSF)**	**110% Original (PSF)**	**120% Original (PSF)**
Bleed Ramp1	82.2	92.5	97.7	102.8	108.0	113.1	123.4
Bleed Ramp2	82.2	92.5	97.7	102.8	108.0	113.1	123.4
Bleed throat lower	716.2	805.8	850.6	895.3	940.1	984.90	1074.4
Bleed throat upper	708.4	797.0	841.3	885.6	929.8	974.1	1062.7
Bleed Cowl	334.4	376.2	397.1	418.0	438.9	459.83	501.6
Side_Fwd	82.2	92.5	97.7	102.8	108.0	113.1	123.4
Side_Thrt	444.2	499.7	527.5	555.2	583.0	610.7	666.3

Updating CFD "baseline" to real-world tunnel conditions

- Subsequent to initial data analysis it was discovered that most recent data files were not corrected for reference pressure.
- $Pressure\downarrow Total = Pressure\downarrow Differenetial +$ $Pressur$ $Pressur$

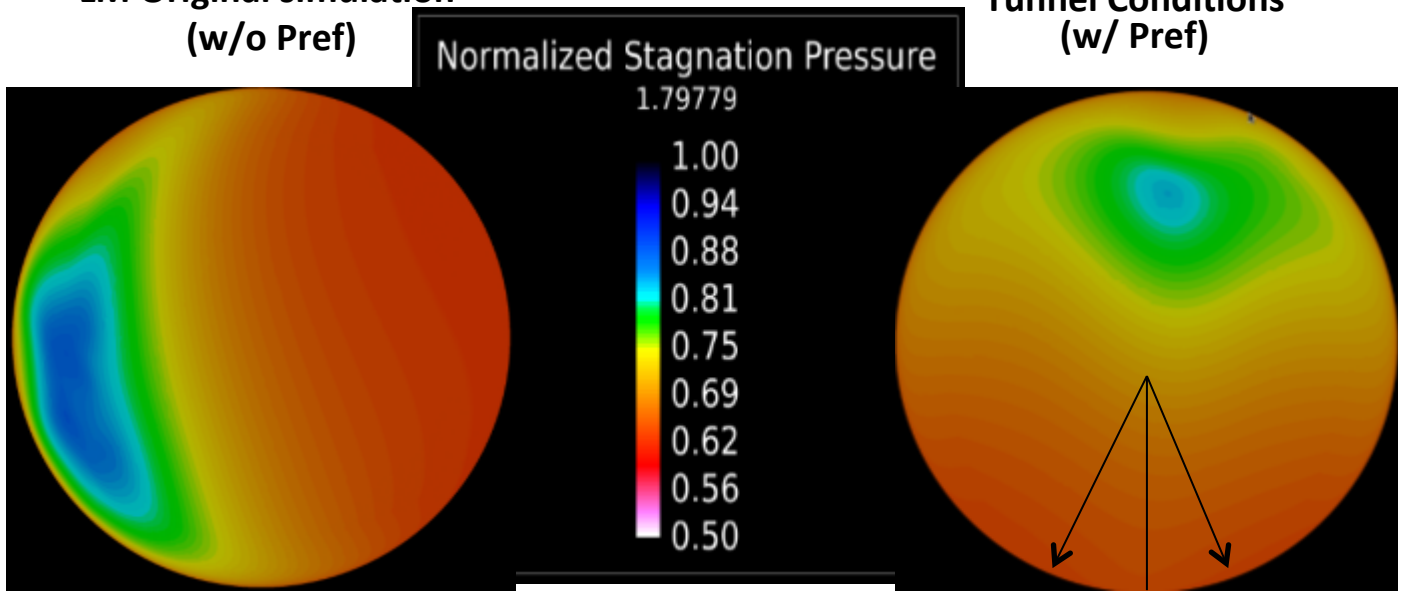
Set/Domain	Original (PSF/PSI)	Tunnel (PSF/PSI)
Ramp Bleed #1	102.86/0.71	185.41/1.29
Ramp Bleed #2	102.86/0.71	185.41/1.29
Lower Isolator	895.37/6.22	978.48/6.80
Upper Isolator	885.60/6.15	967.73/6.72
Cowl Bleed	418.03/2.19	501.16/3.48
Fwd Side Bleed*	102.86/0.71	95.72/0.66
Isolator Side Bleed	555.26/3.86	638.40/4.43

*Original LM simulation used an incorrect pressure

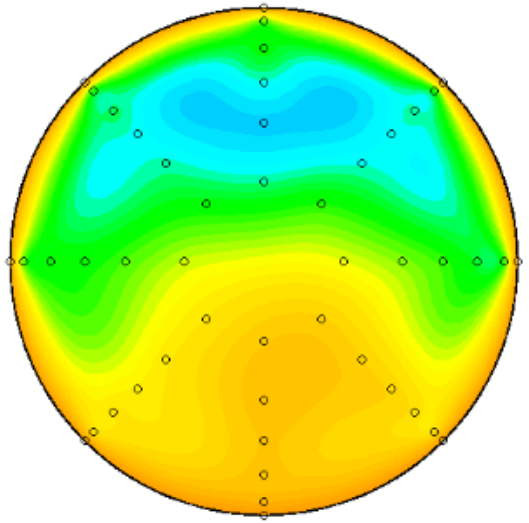
Comparing LM baseline run (2013) to AFRL FALCON simulation with Pref added (2015)

LM Original simulation (w/o Pref)

Tunnel Conditions (w/ Pref)



AFRL experimental run (experimental Interpolation)



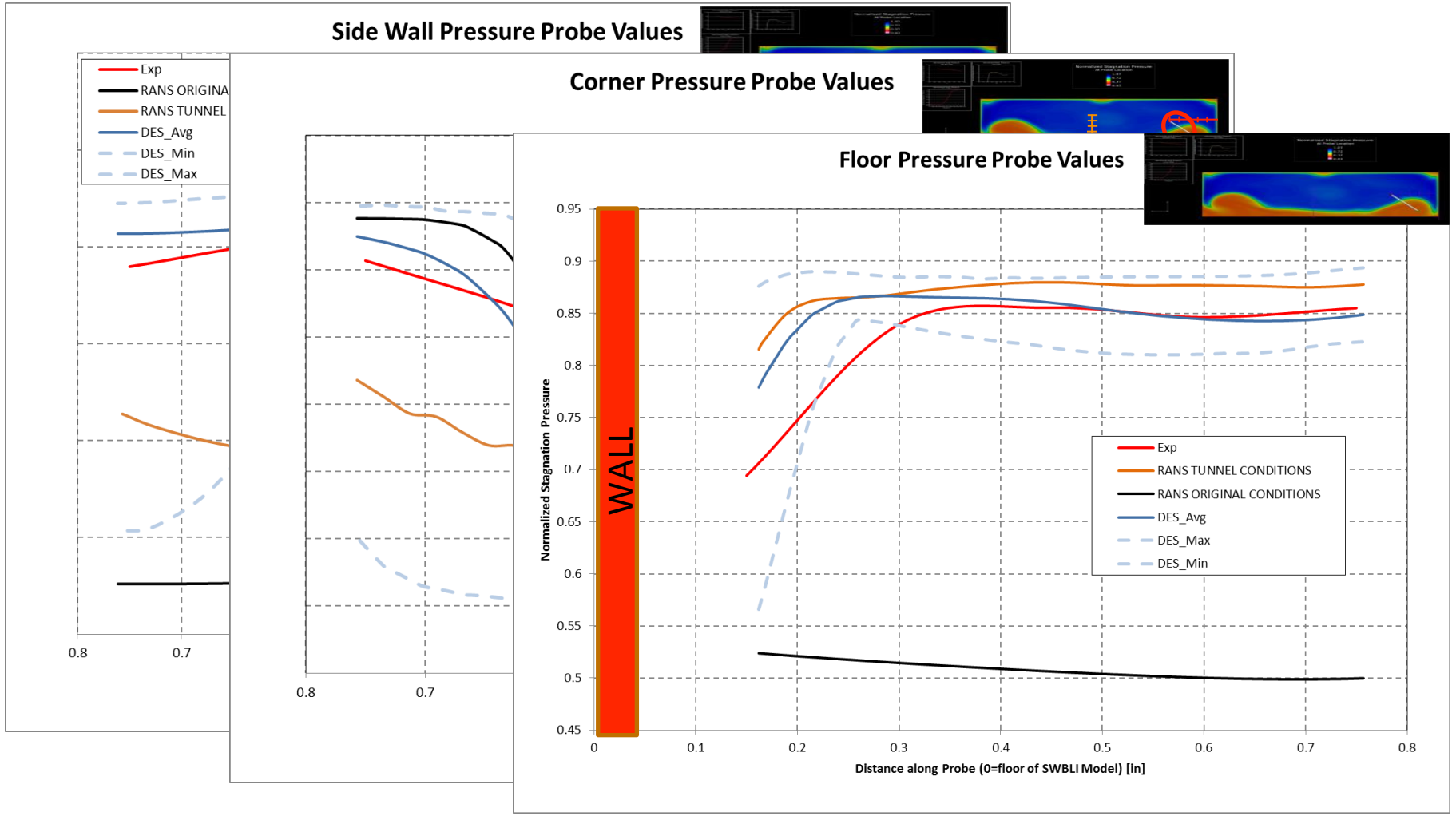
LM Baseline Simulation: Single low pressure region on the right which is directly correlated to the asymmetric corner separation. (PR @ AIP = 68.3%)

Tunnel Conditions Simulation: The low pressures region has relocated to the bottom of the AIP face. Symmetric corner separations that form on the ramp do not fully merge resulting in two low pressure regions. (PR @ AIP = ~70.9%)

AFRL experimental run: Corner vortices here seem to have merged into on low pressure region at bottom dead center. (PR @ AIP = ~76.4%)

plot created using 40 point experimental results and a bi-harmonic spline interpolation

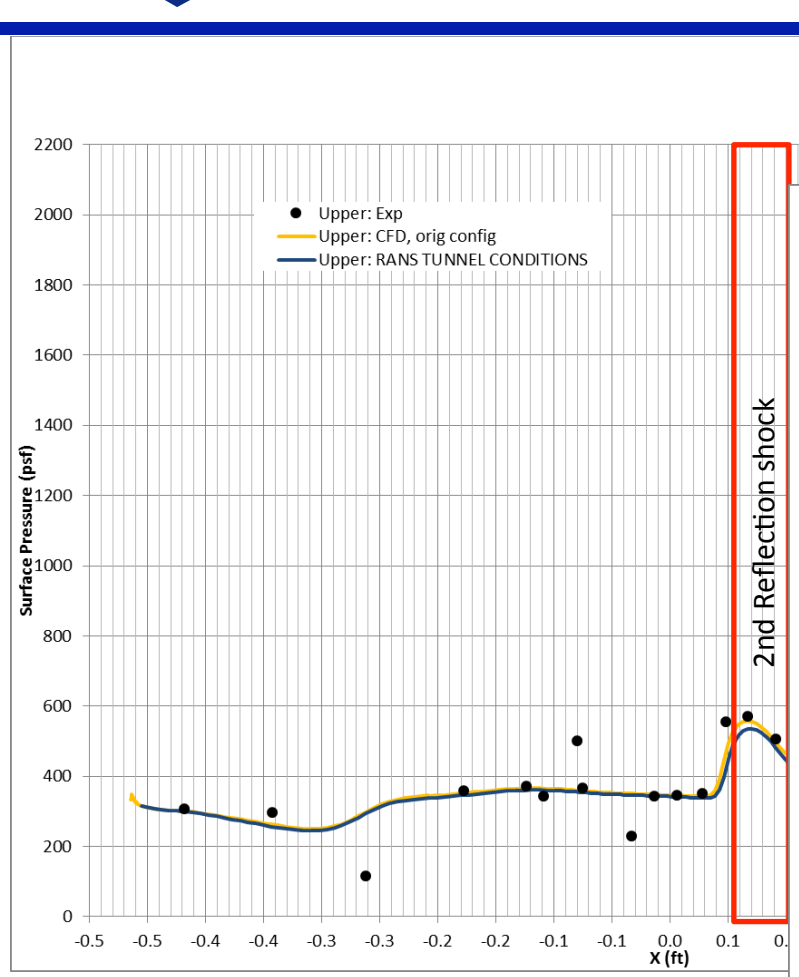
Subsonic Diffuser Throat Rakes Experimental and FALCON CFD Comparison

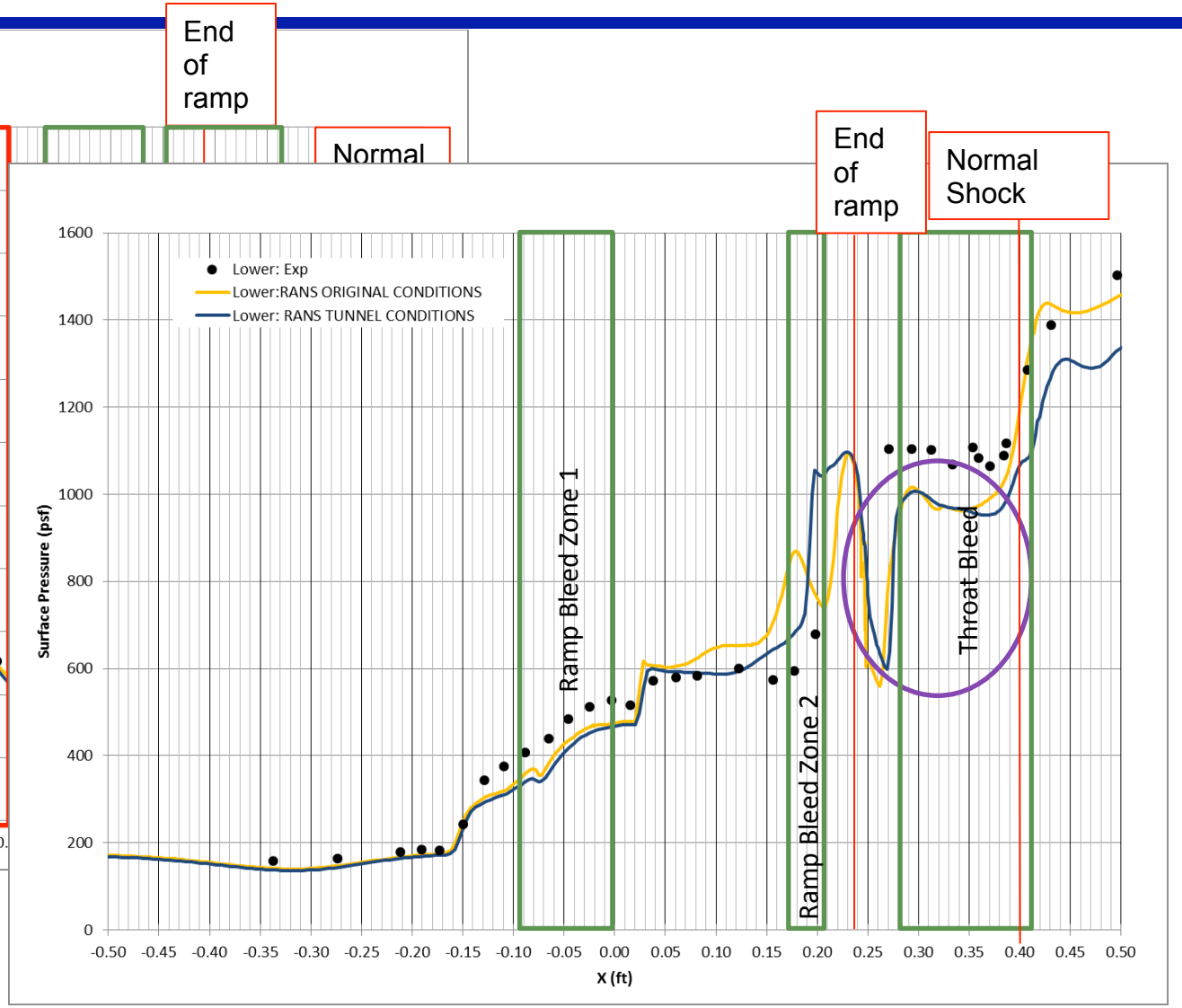


- DES AVG remains only comparable result at side wall location
- RANS TUNNEL conditions compare better at corner location
- Wash between RANS TUNNEL and DES AVG at floor centerline position
- RANS TUNNEL >RANS ORIGINAL at all locations
- No simulation technique has capturing the complete flow field structure correctly

RANS Original & DES AVG = Incorrect Total Pressures
RANS Tunnel = CorrectedTotal Pressure

Comparing Upper and Lower Centerline Surface Pressures to Experimental Values Obtained in SWBLI MODEL



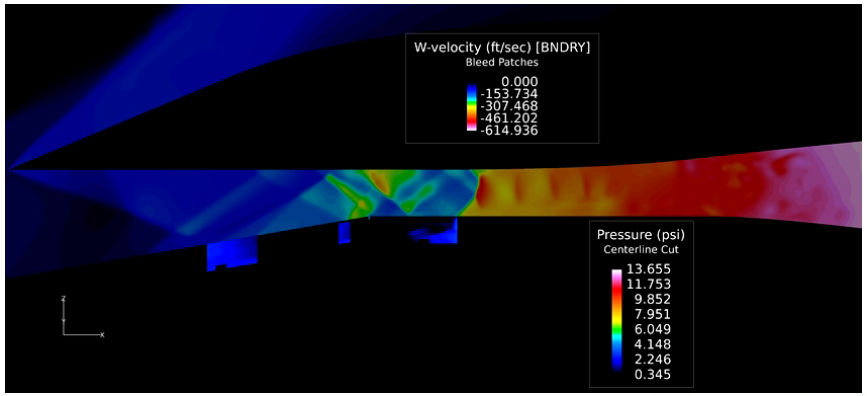


The updated RANS simulation matches well with the experimental centerline pressures except where circled at the left. The CFD grid models the exact gap in the experiment. Calculations show this backward, forward facing gap as a much larger issue than found experimentally

Problems with DES simulations

The SWBLI model has it's peak performance when it is back pressured close to inlet unstart.

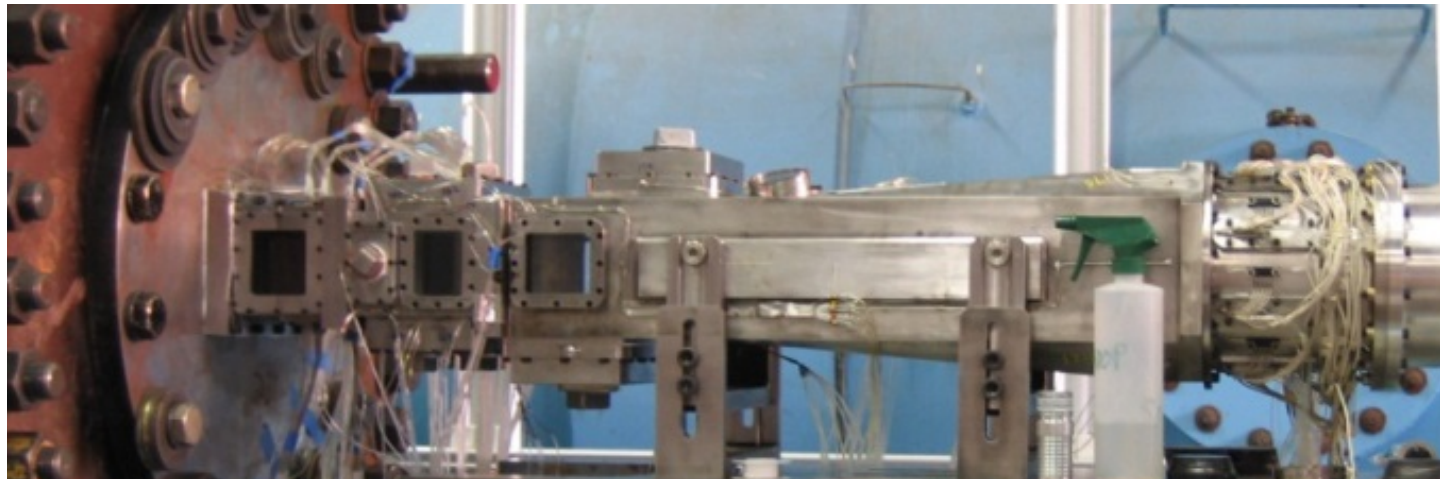
- **This proximity to unstart is difficult on DES solvers due to the dynamic nature of the shock moving around at initiation and the effects of the near unstart remain for several thousand iterations**
  - **One possibility is the solver unstarts the inlet and all the of data/computing time is wasted**
  - **Another possibility is the solver doesn't unstart, though comes close, and in order to provide enough samples to average over the solution needs to be run for long periods of time**
  - **Finally the third is that everything works as hoped**
- **AFRL has run 6 DES simulations at the corrected tunnel conditions, 4 unstarted, 2 nearly unstarted***
  - *** Near unstarts only worked after increasing bleed mass flow**

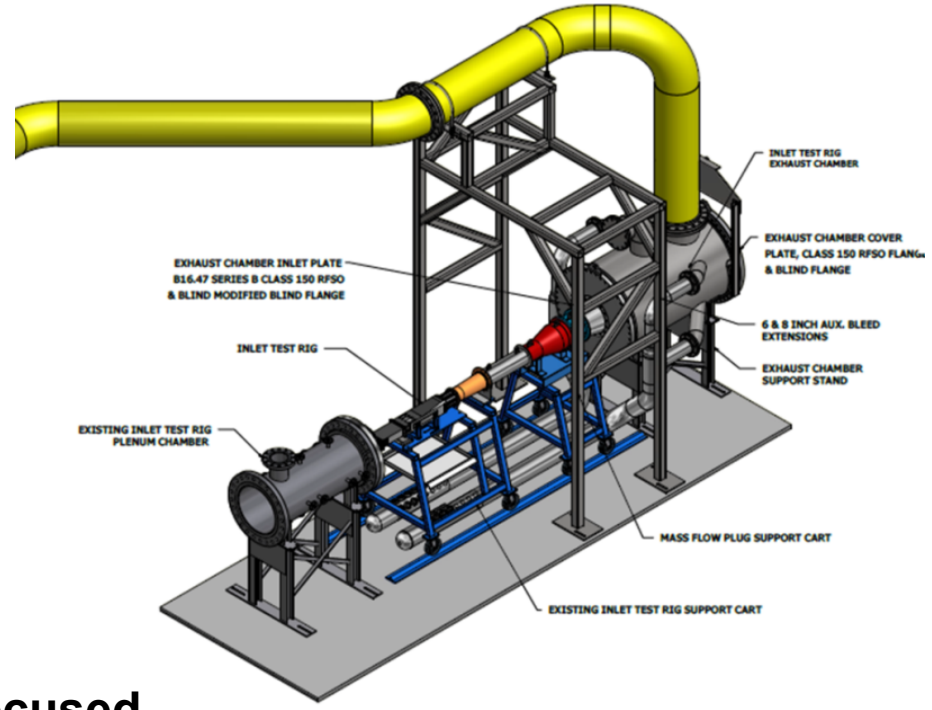


Lessons Learned

- Updating the bleed conditions in FALCON results in a much improved flow field, though current versions still have problems with some details
  - Bleed plenums must include more pressure instrumentation to document how the plenum pressure is distributed.
  - Including more non-centerline taps would be worthwhile.
  - SWBLI RANS results have pressure recovery loss due to ramp hinge effects whereas experimental results do not show this effect.
  - CFD results agree well going into the subsonic diffuser but agreement diminish through the subsonic diffuser
  - DES simulations at optimal shock location and back pressures are difficult to simulate because of DES variability during initiation
- SWBLI isolator bleeds on the ramp and cowl surfaces show very high plenum pressures and plenum exhausts need to be redesigned

Advanced Diffuser Aperture Control (ADAC) Facility



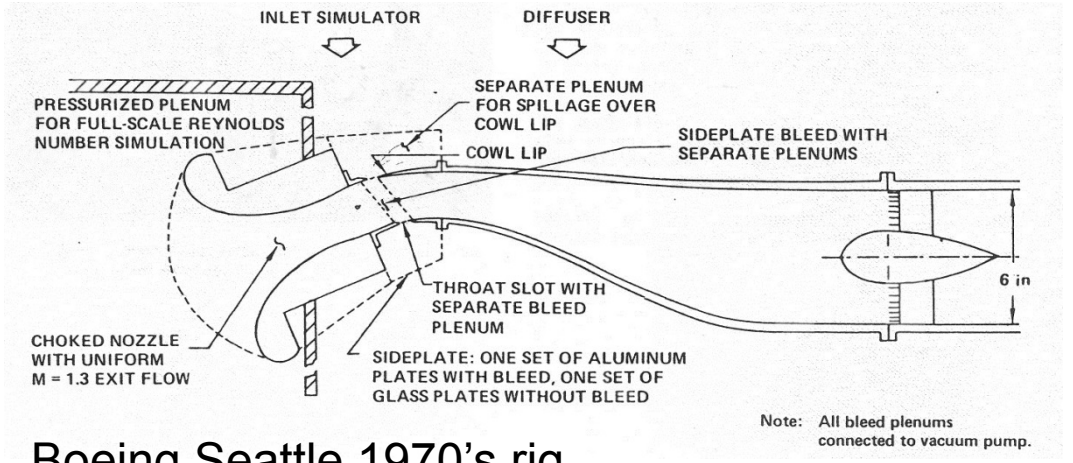


SPIRIT-ADAC Test Facility

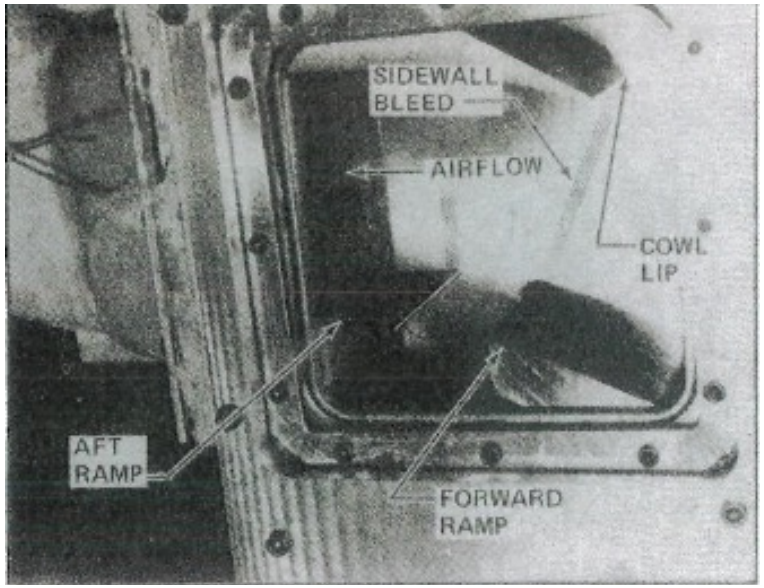
- **ADAC facility (Boeing TRICS) originally mixed compression focused**
- **Test cell infrastructure completed, exhaust tank, exhaust lines and flow plug design**

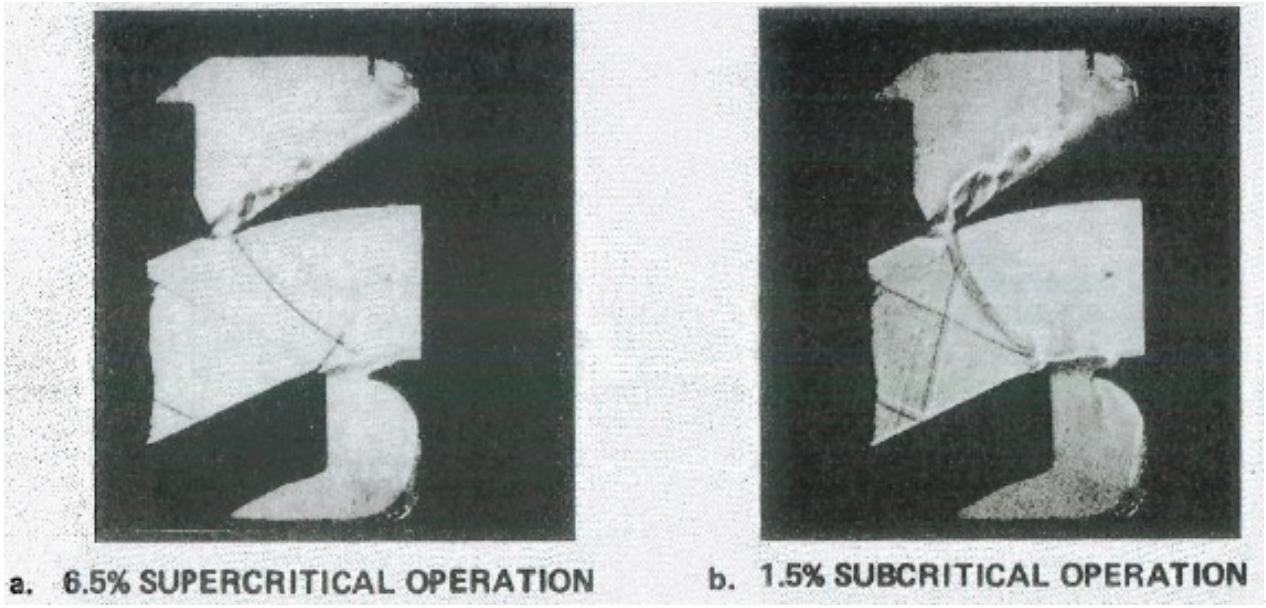
ADAC Facility Redesign

- Redesigning flow path to include spill over cowl and possible side plates
- Starting with 2-D supersonic geometry but may eventually move to 3-D
- Starting with benign diffuser but will move to flow control enabled offset ducts



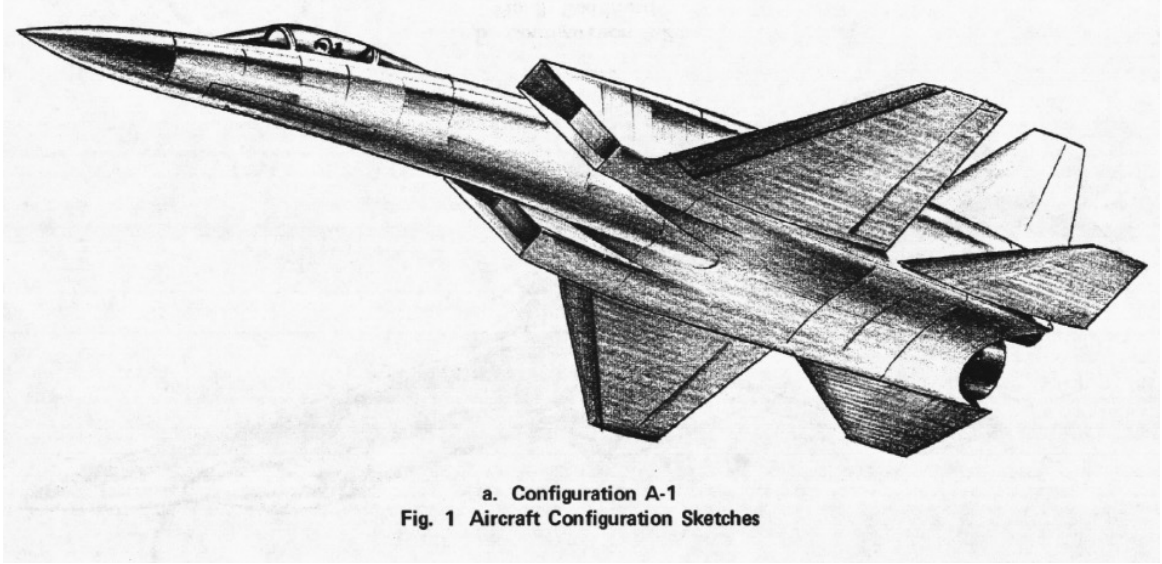
Boeing Seattle 1970's rig



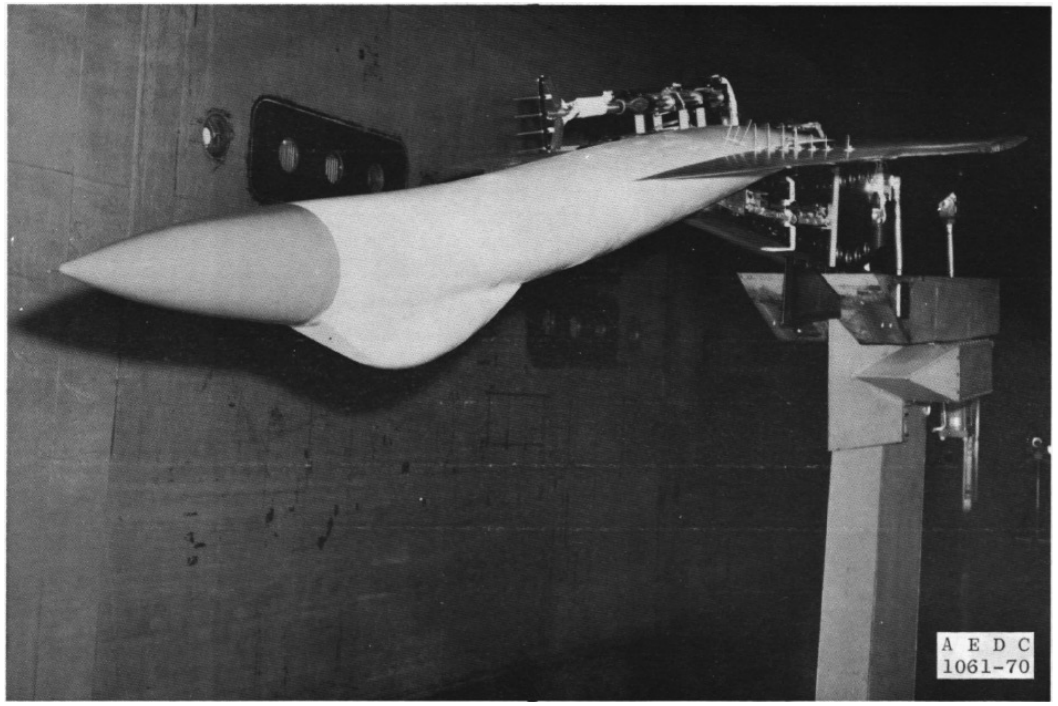


ADAC Facility Inlet Geometry

- Investigated developing parent flow field using SUPIN
- Now considering Tailor-Mate A-4 geometry because of 16S & 16T test data which includes alpha and beta sweeps with approach flow fields and numerous duct station flow fields



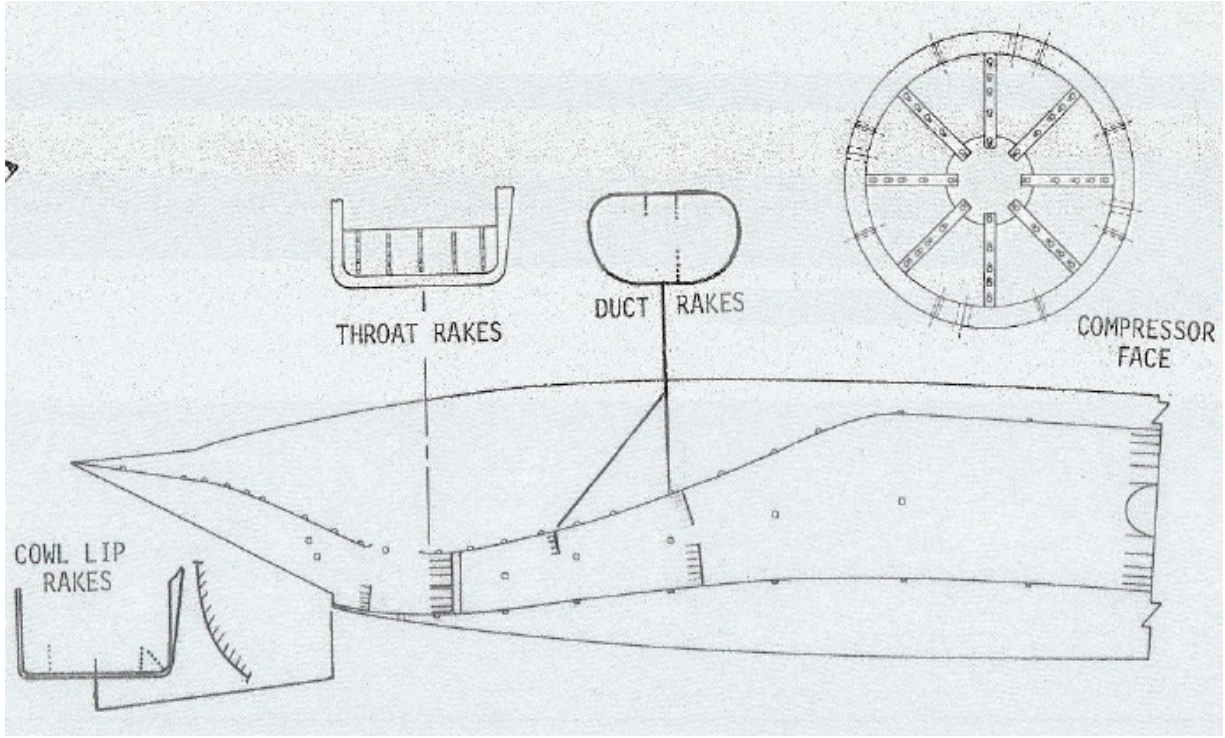
a. Configuration A-1
Fig. 1 Aircraft Configuration Sketches



- 5-Hole probe flow angularity data for inlet approach flow field which includes alpha and beta sweeps

Tailor-Mate Data Set

- Tailor-Mate A-4 data set includes alpha and beta sweeps with throat rakes and numerous duct station Rakes.
- All original fabrication drawings and models lost to history.
- CFD geometry that was run in the 80's is also unavailable.
- Attempting to recover geometry by combining incomplete geometry definition in various reports with small scale drawings.

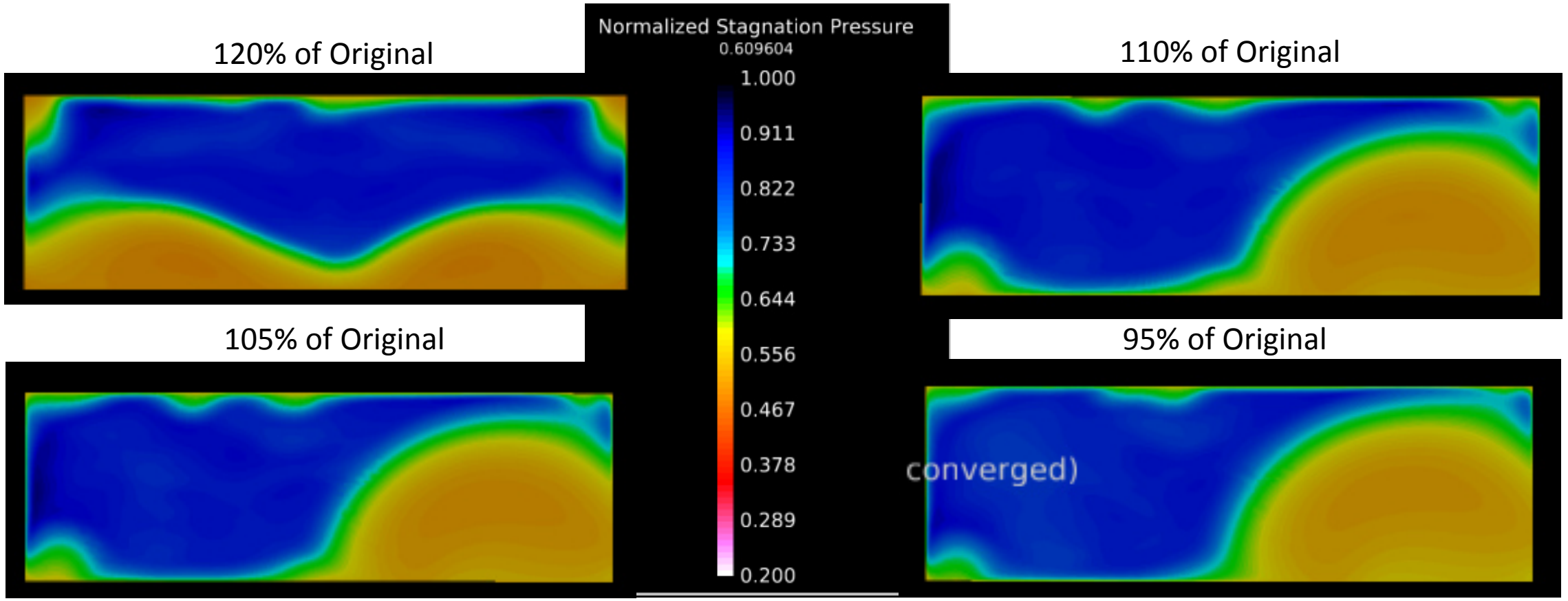


- Using the extensive Tailor-Mate data set we are considering ways to determine installation effects using the ADAC rig by experimentally replicating CFD determined inlet aperture approach conditions
- Some of the ideas we are exploring include SLA honeycombs in the throat region and facility nozzle throat skewing via air jets.

Backup Slides

Bleed Sensitivity

Below is a series of images detailing how the flow changes with the previously listed changes in bleed plenum.
*Note that the 90% and 80% simulations would not converge



These results lead AFRL to investigate the bleed plenum pressures recorded in the experimental values