1MW Horn Stripline + Air Diverter Wind-Tunnel Testing

Cory Crowley, George Lolov, & Lionel Pittman

TSD Topical Meeting

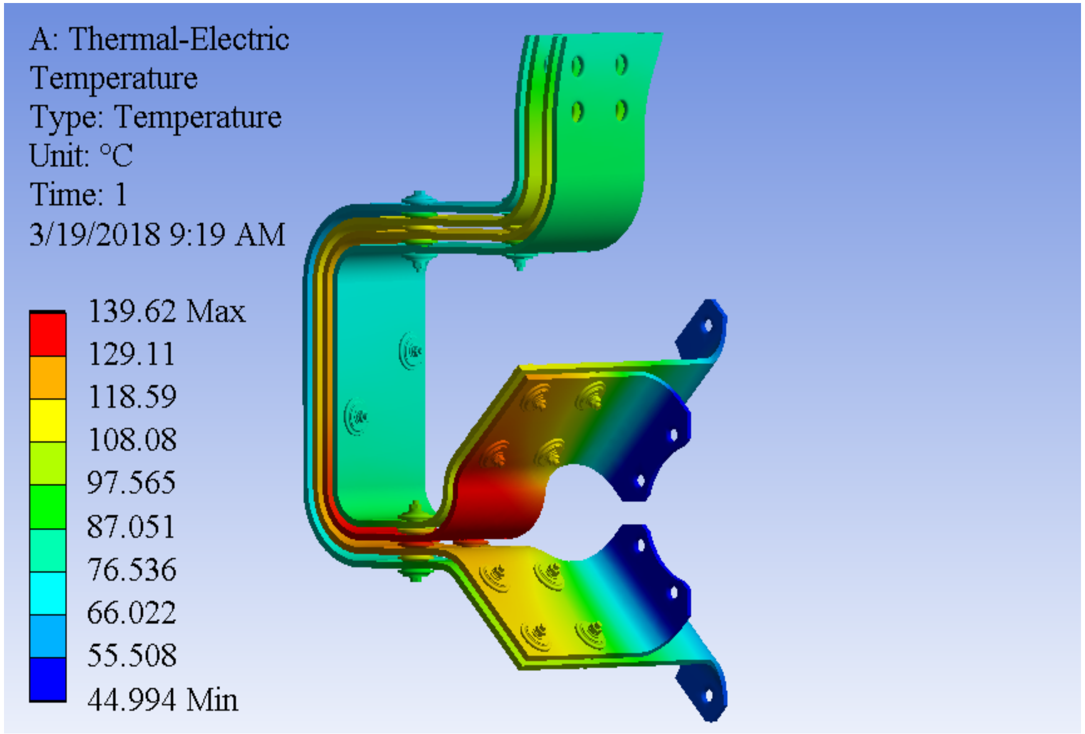
2/28/2019

Outline

- Cory
  - 1MW Stripline Motivation & Requirements
  - Testing & Design Goals
  - T-Block Air Diverter
- George
  - Testing Setups
  - Upgraded Diverter Design
  - Data Acquisition / Analysis
- Cory + George
  - Current Status

1MW Stripline Motivation & Requirements

- Existing 700kW stripline & air diverter system is not a viable solution at 1MW.
- Max stripline temperature desired to be less than 100C at any point.
- Must maintain 100,000,000 pulse lifetime requirement. Temperature & resultant material creep makes pulse life determination impossible.



Analysis Credit: Zhijing Tang

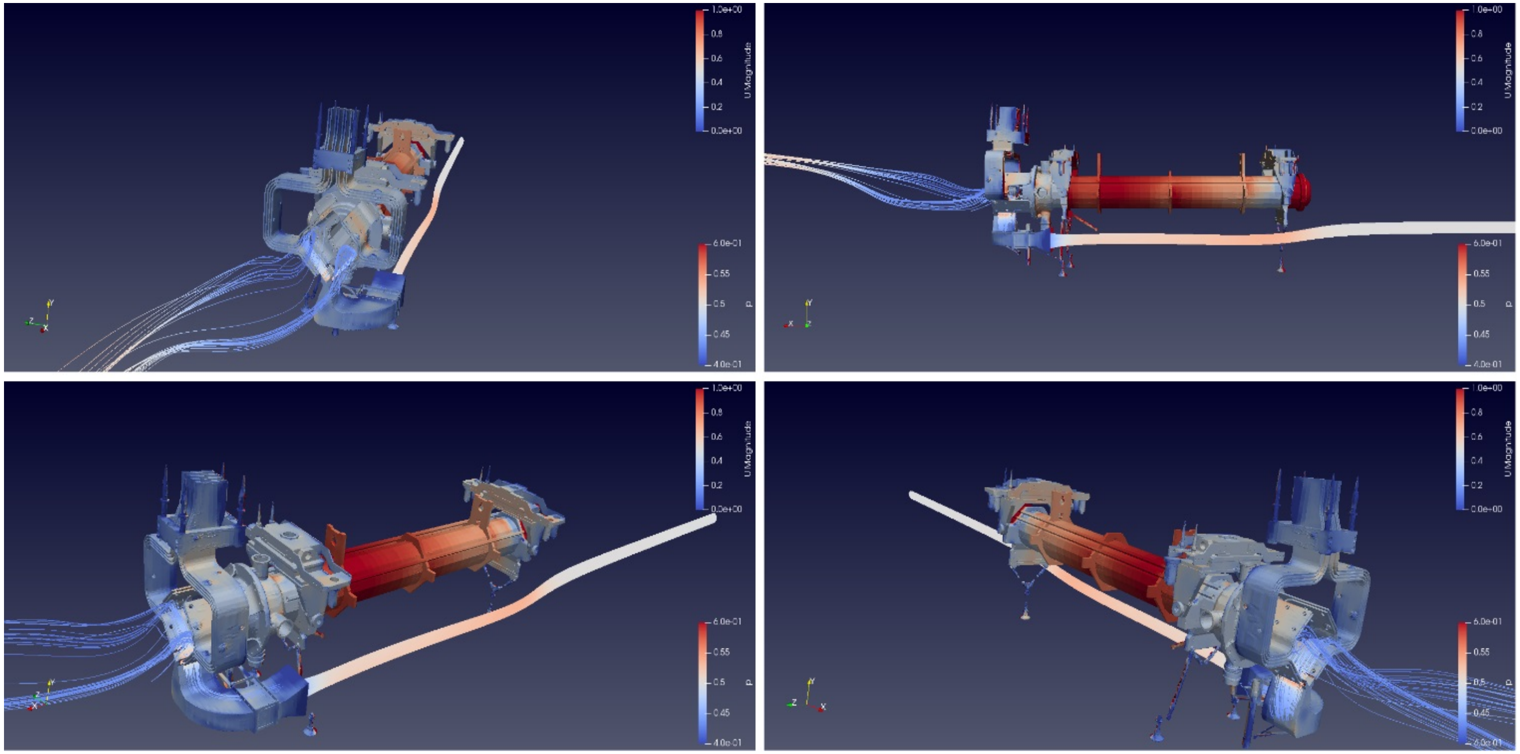
New Stripline

- Must mate to existing NOvA Horn conductor flange geometry.
- Improve material selection where possible (6013 aluminum).
- Improve air cooling to stripline structure.

Testing & Design Goals

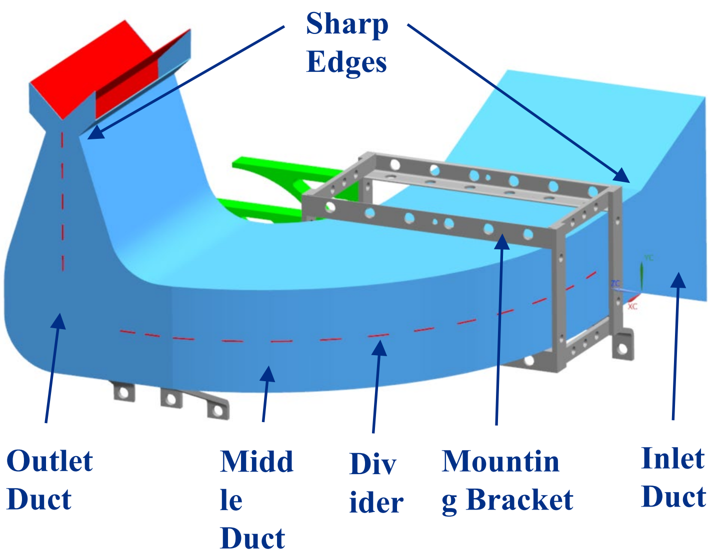
- Understand existing air flow characteristics & heat transfer.
- Identify improvements to existing structures & verify through iterative theoretical & experimental testing.
- Verify conclusions and final production design with repeat wind tunnel & heat transfer test.

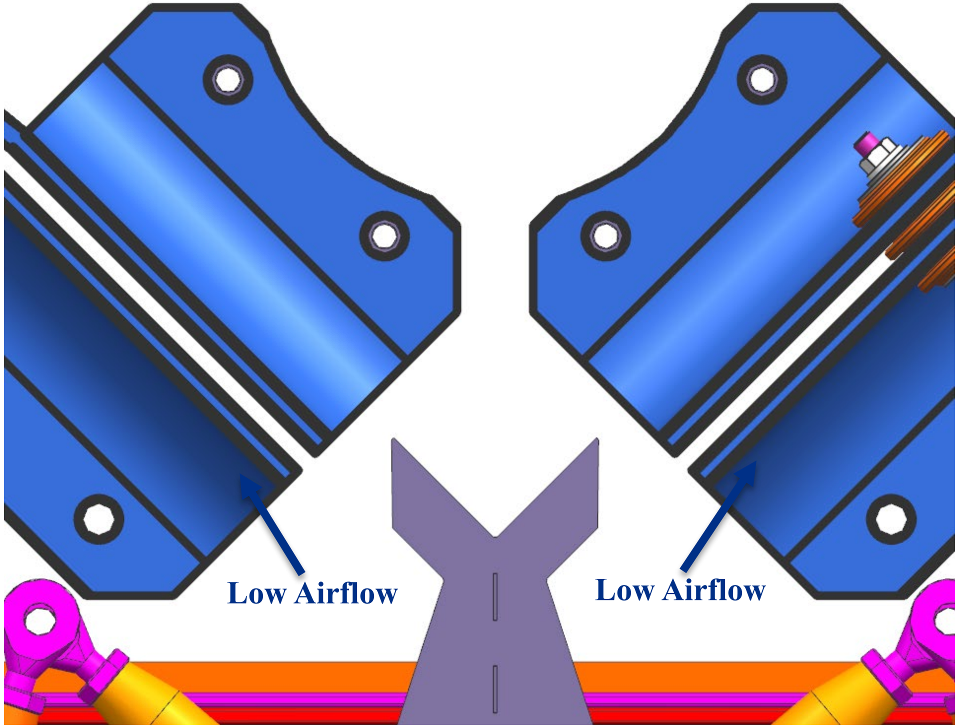
Analysis Credit: Lionel Pittman



CFD Conclusions of Existing Diverter

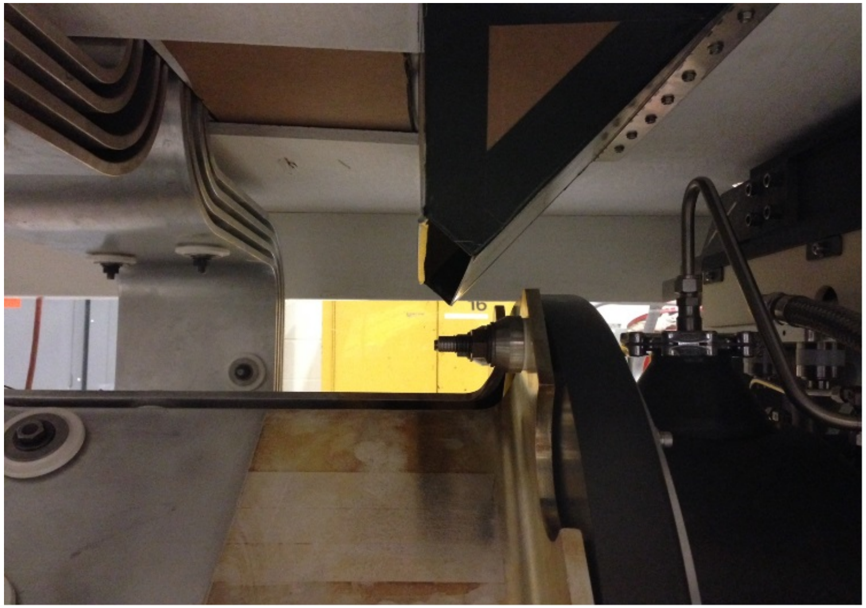
- Provides good flow for inner lower flags; moderate flow for inner upper flags.
- Sharp edges and pinch points appear to impeded air velocity.
- Initial thoughts were that they created eddy currents to improve flow.
- Theoretical simulations show these can be improved (George to discuss further).

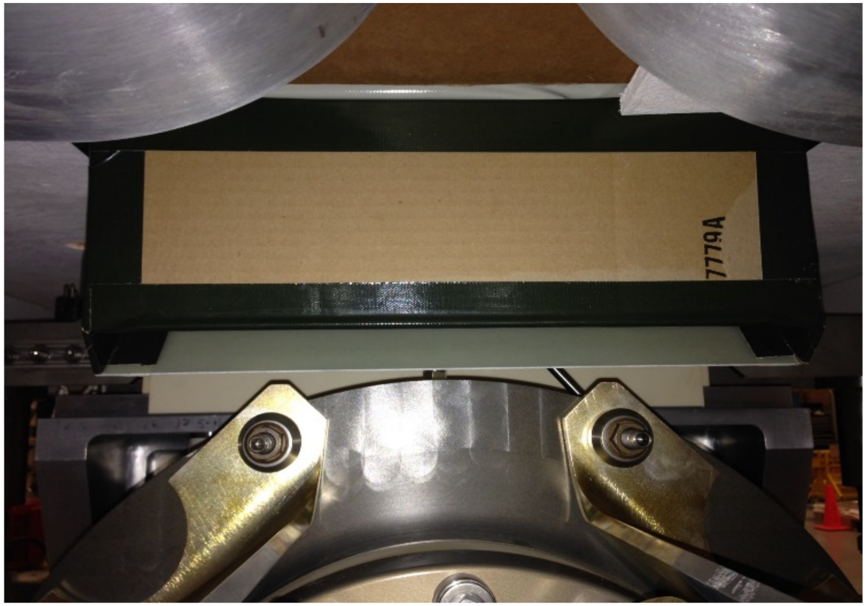




T-Block Air Diverter

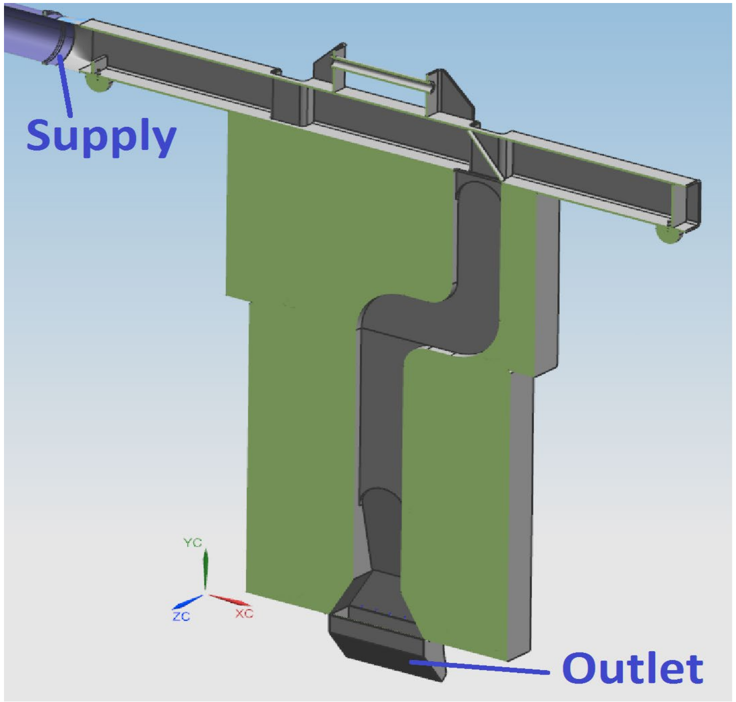
- Solution needed to address stripline upper flags and vertical side spans.
- Two realistic solutions:
  - Pipe air down through stripline block.
  - Dedicate T-block with internal duct.
- Internal duct chosen because of direct access to hot upper flags.
- Air deflection from T-block appears to greatly help vertical side spans as well.
- Multiple diverter angles tested; winner is 45 degrees at ~600 CFM.

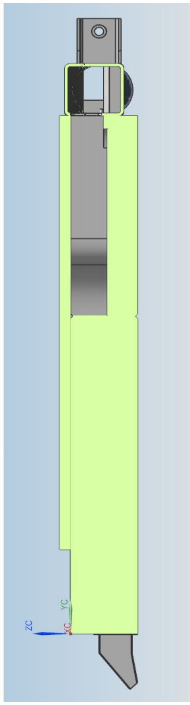


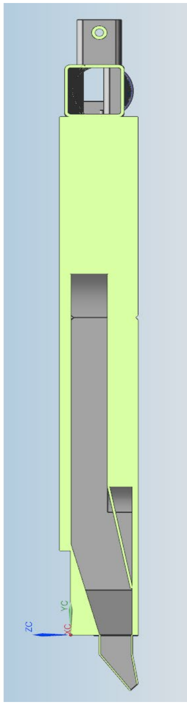


T-Block Air Diverter

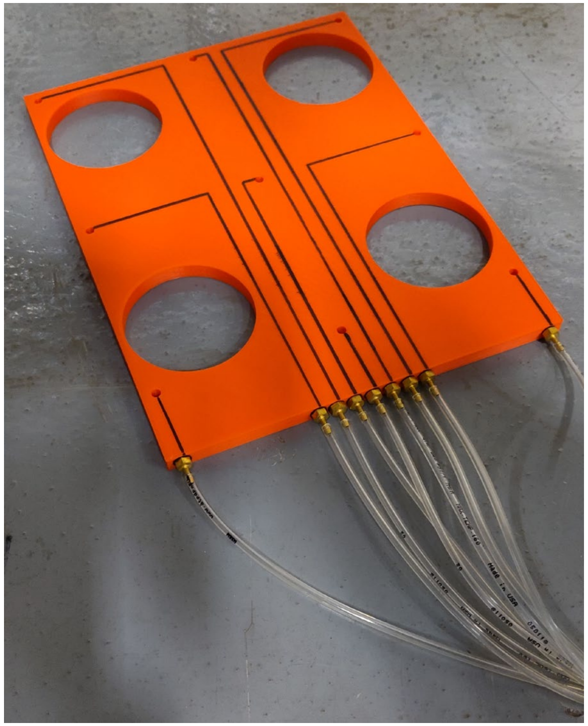
- Drop in replacement T-block.
- Channel dimensions minimized (8” wide X 4” deep).
- Labyrinth dogleg direction is opposite that of stripline block to minimize effect on shielding.
- Supply fed through structural box beam support on beam left & will employ quick disconnect coupling.

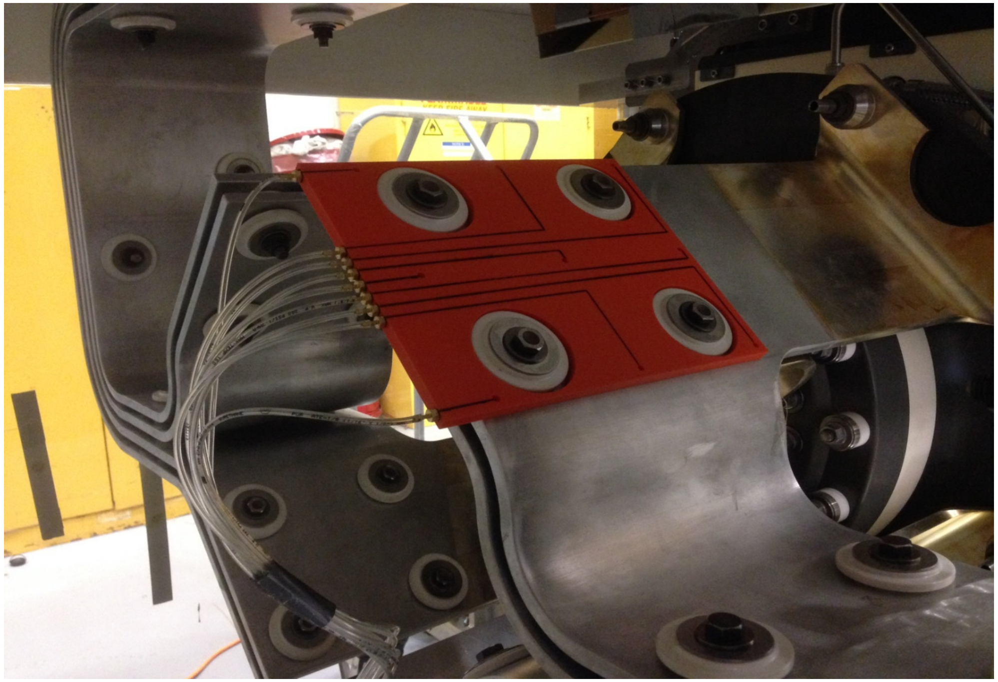


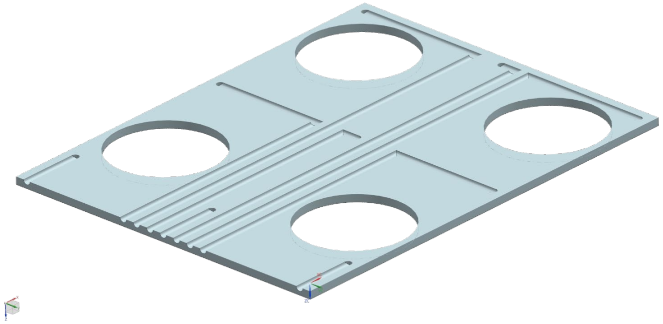




Test Setup - Pressure Testing Trials



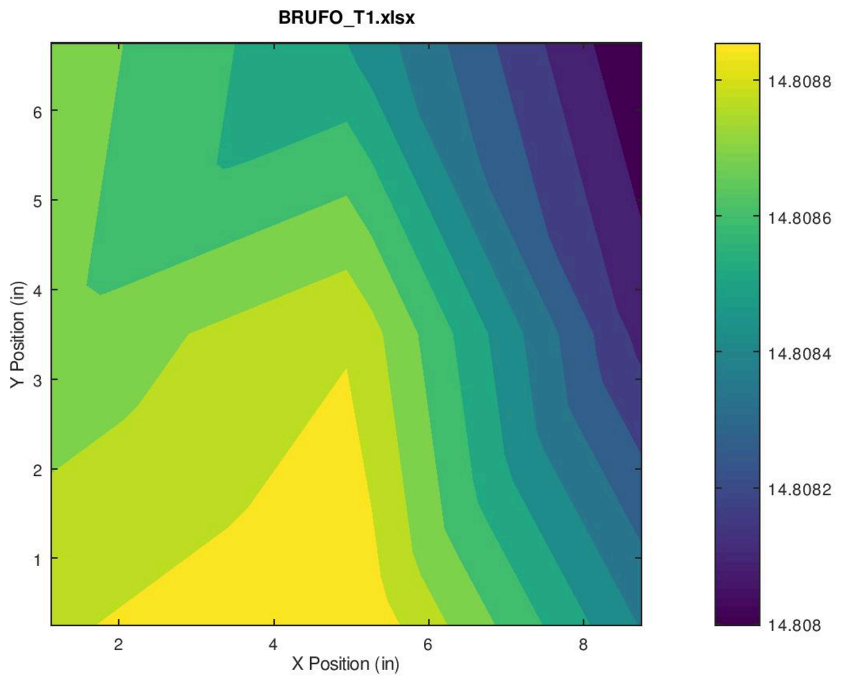


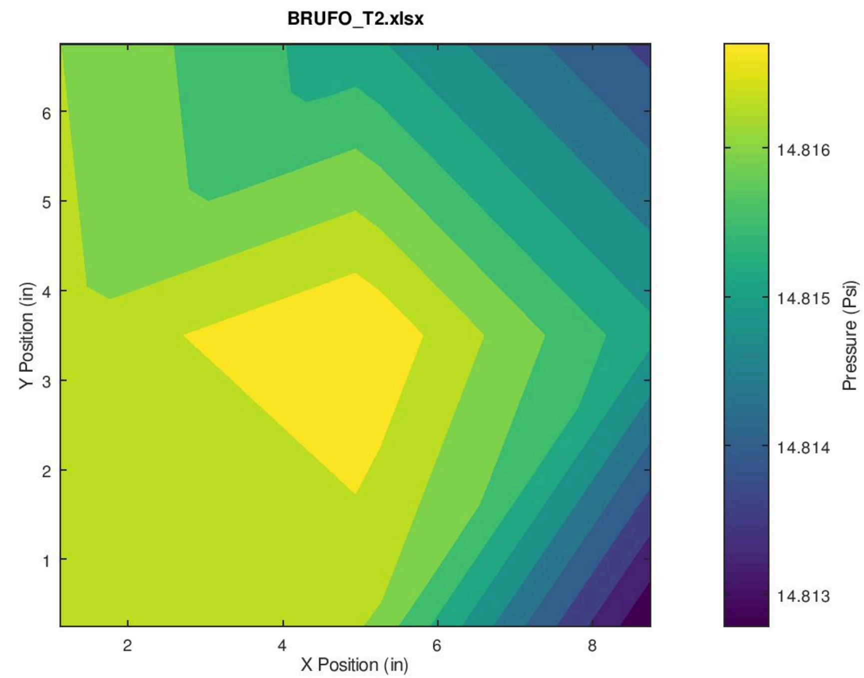


- Fixed on each of the 8 flag faces and measured airflow pressure at 9 locations on the flag surfaces

Pressure Testing

- Ran pressure tests for each iteration of the top and bottom diverters.
- Results mostly inconclusive. Pressure drop not large enough to provide reliable data.

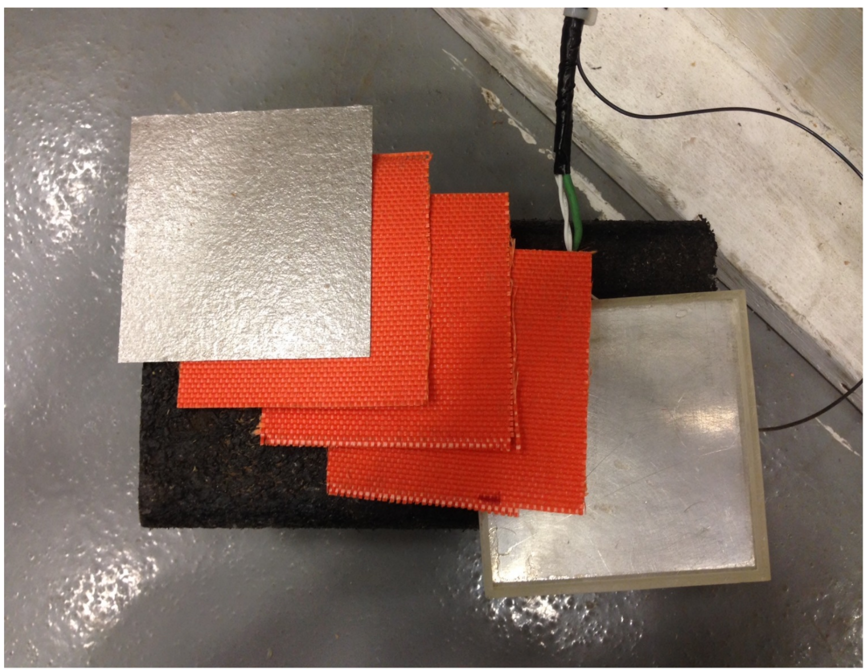


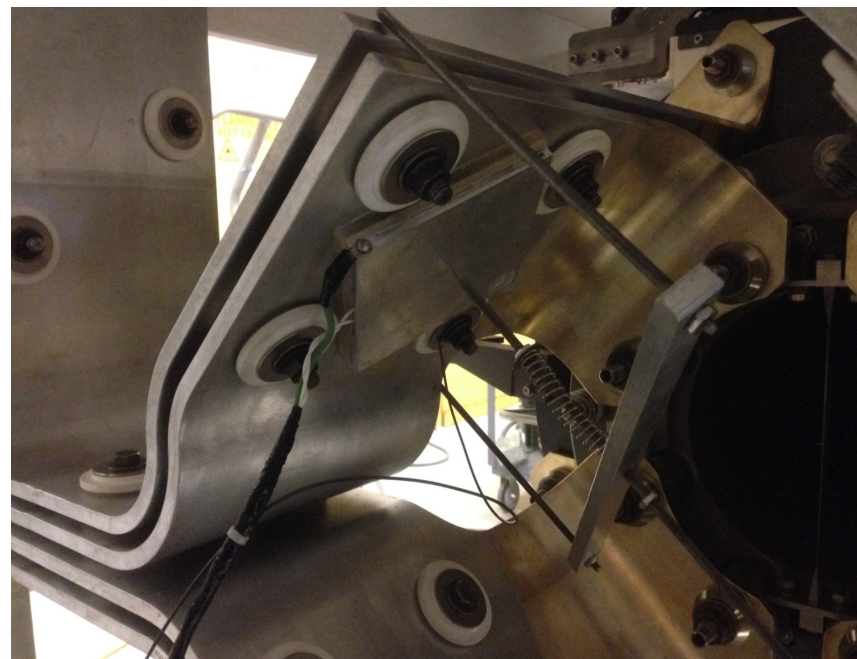


Fermilab

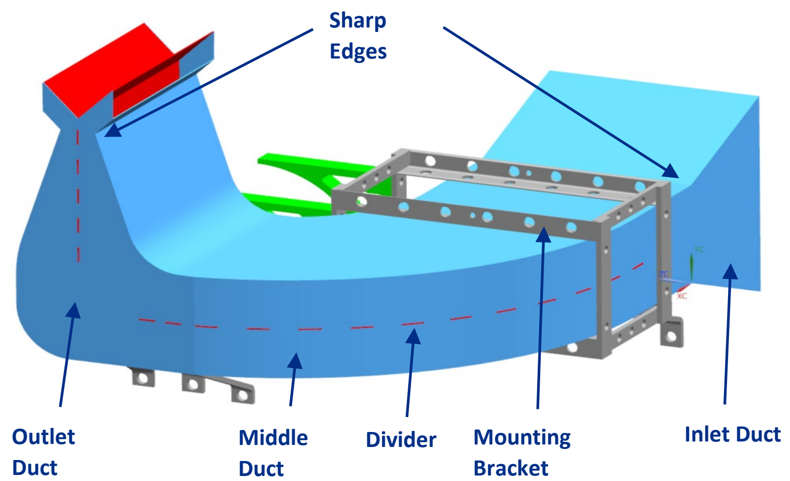
Convection Coefficient Testing

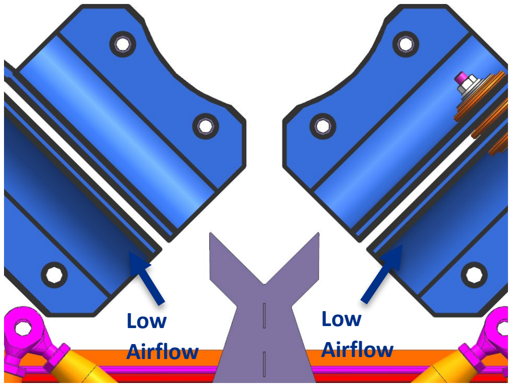
- Al coupon with heating pad and thermocouple inside.
- Set on each of the flag faces, set to 80W, turned on the airflow, observed cooling curve.
- Identical to original method used, with slightly improved thermal isolation of coupon.

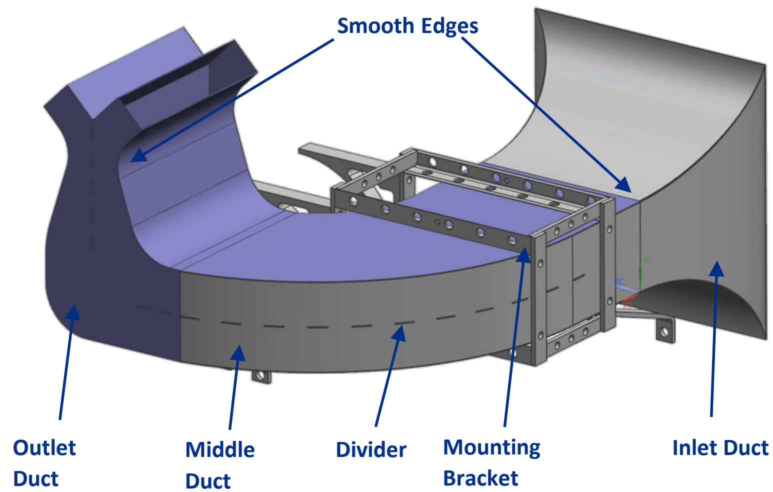


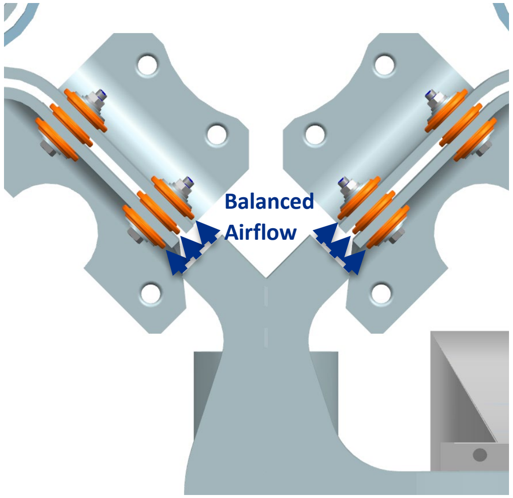


Old / New Diverter Comparison



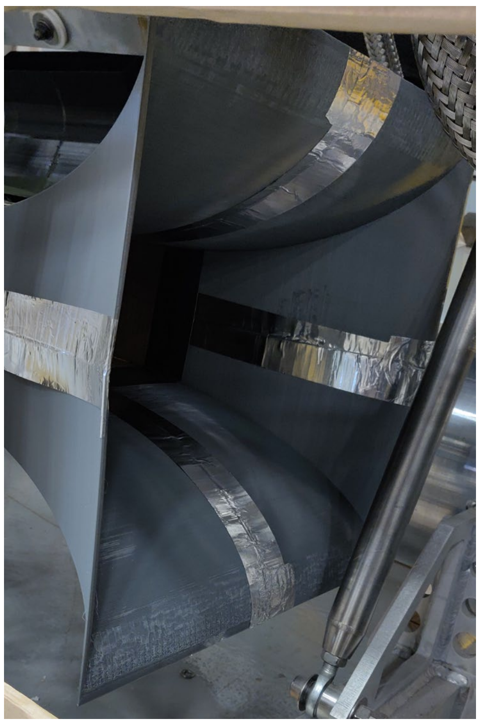


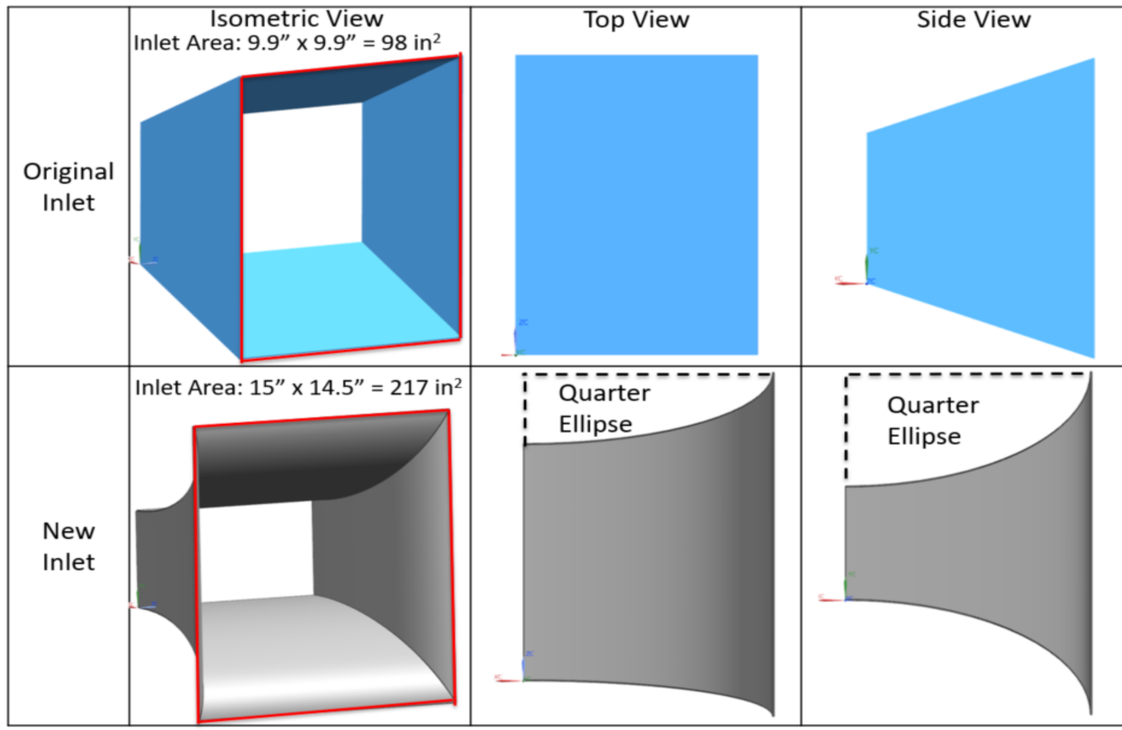




New Diverter Design

- New Inlet features 4 sheets curved into elliptical geometry.
- Initially tried creating from cardboard- didn't turn out so well.
- Split into 4 sections and 3D printed – worked really well (Thanks Keith!)





New Diverter Design: Inlet

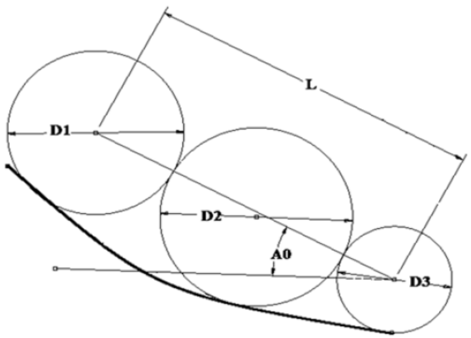


Fig. 1: Profile constructed by three circles approach.

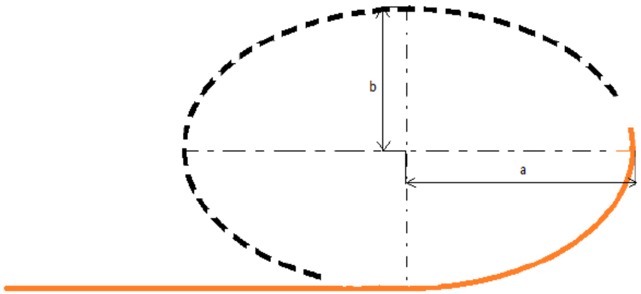
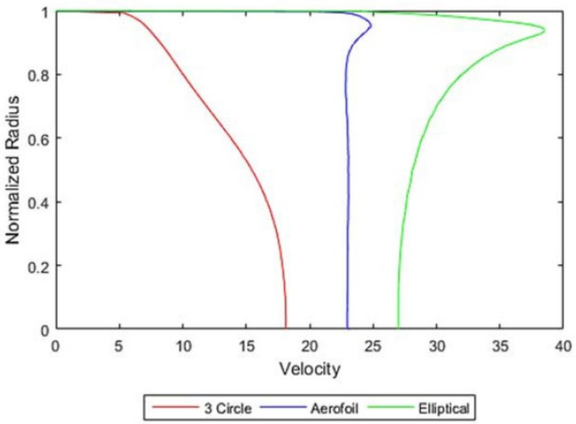
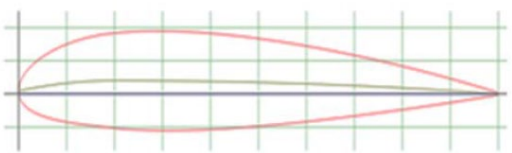


Fig. 4 Profile showing the elliptical region with the straight throat





(a) Camber: 2% (NACA 2412)

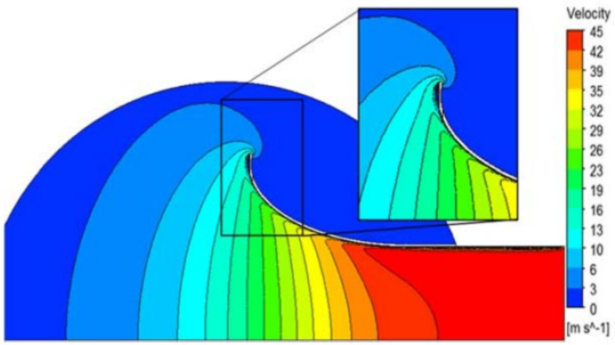
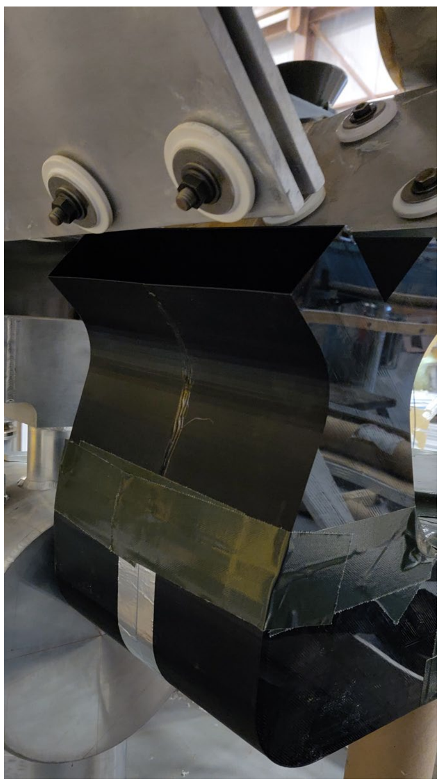


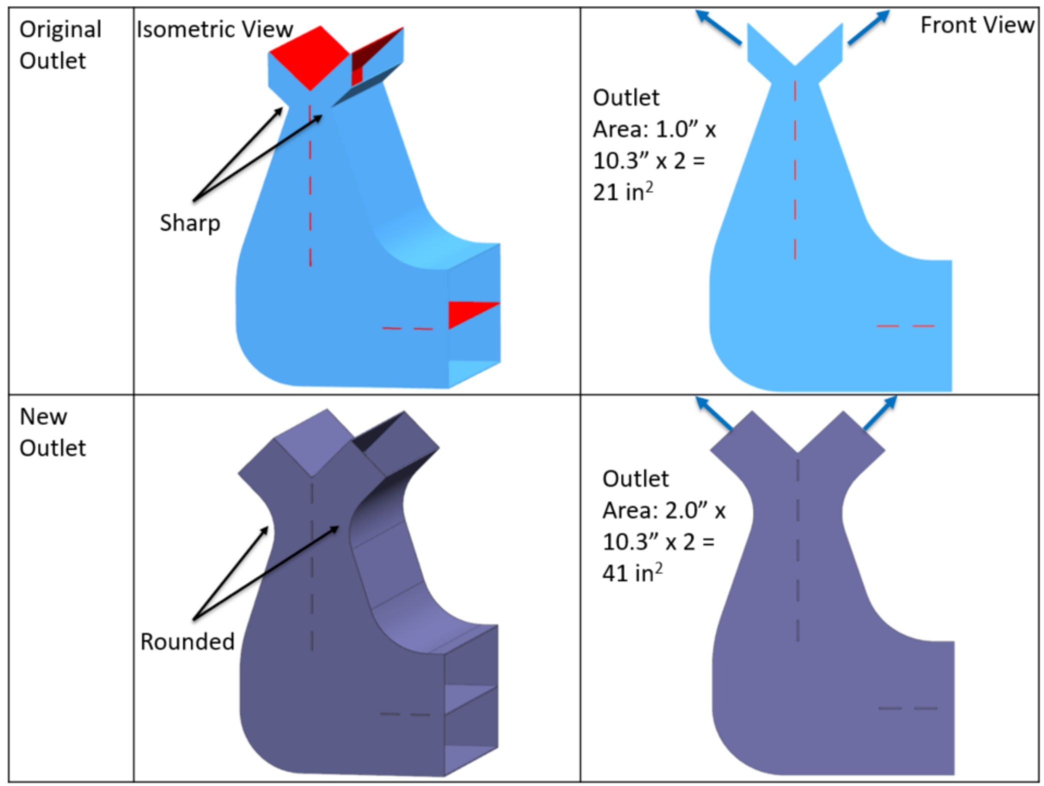
Fig. 17: Velocity Contour of initial Ellipse Profile

DEVELOPMENT OF BELL MOUTH FOR LOW SPEED AXIAL FLOW COMPRESSOR TESTING FACILITY
Apurva Tiwari Et al.

New Diverter Design: Outlet

- Because we doubled the inlet area, we also doubled the outlet area – airflow covers more flag surface area.
- Didn't bother with cardboard, split up into 4 pieces and 3D printed.





Diverter Prototype

3D Printed Inlet

Strategically Placed Counterweight using Principles of Statics

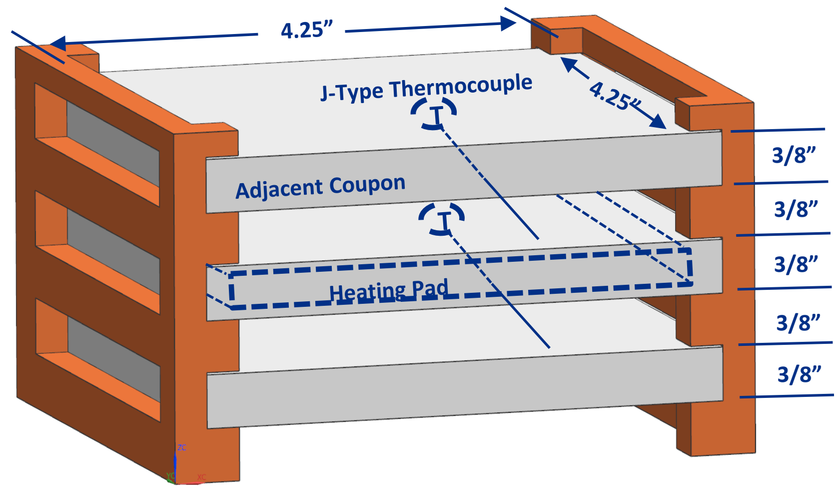
Cardboard Middle Section with Cardboard Divider

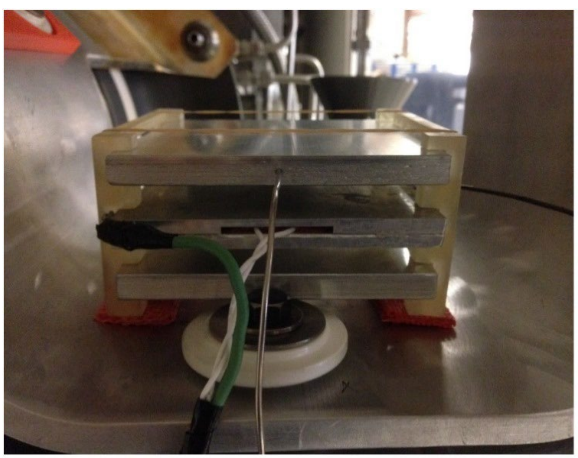
Highly Engineered Support Structure

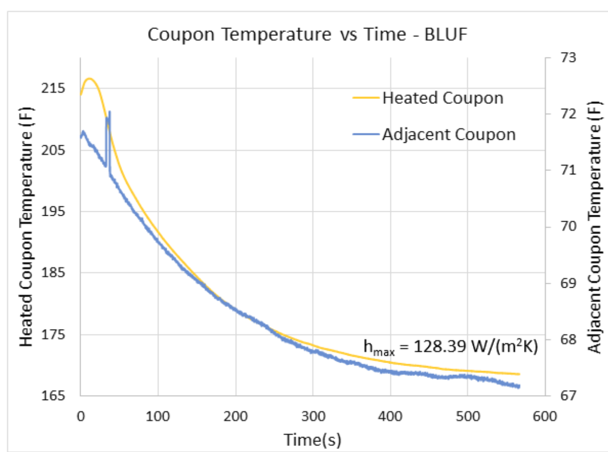
3D Printed Outlet

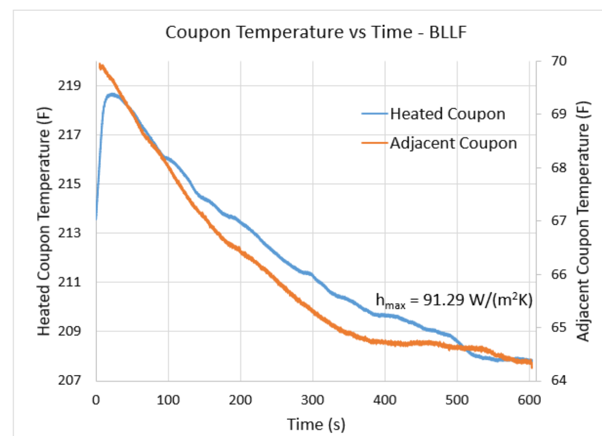
Convection Coefficient Testing

- Assumed stagnant air convection coefficient between the striplines unless proven otherwise.
- Simulations showed inner stripline temps to be too high.
- Experimentally determined convection coefficient for most problematic areas.



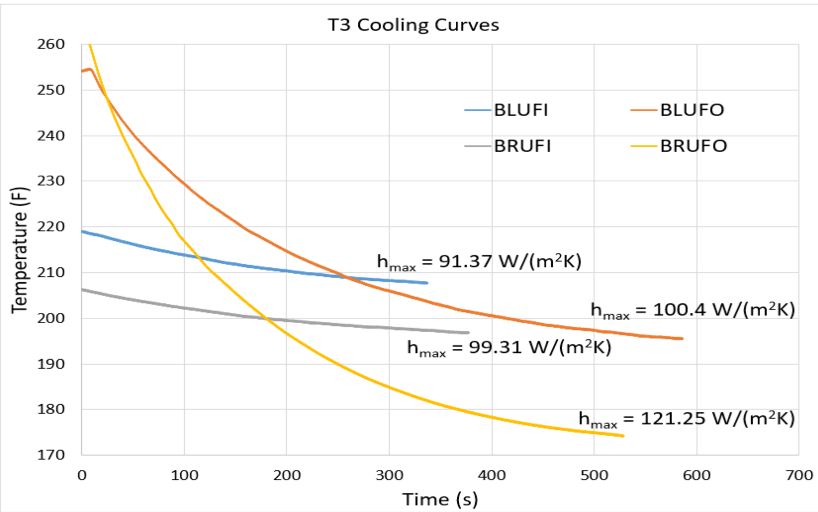


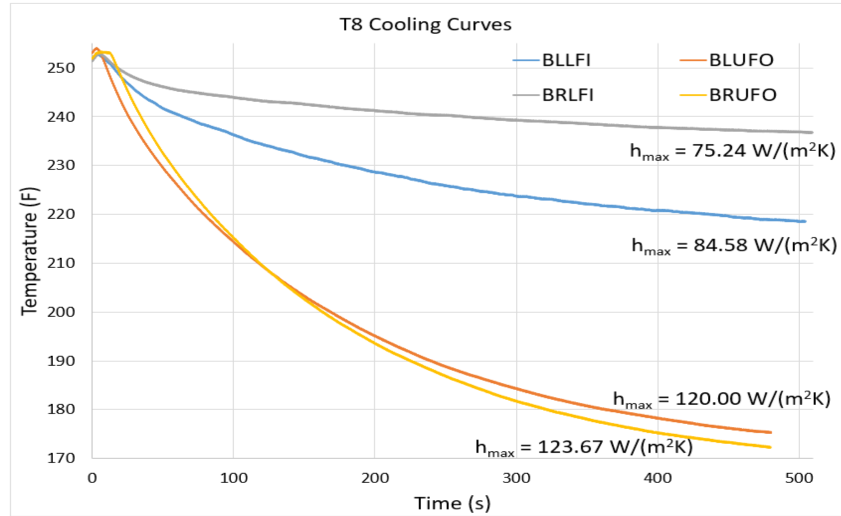




Convection Coefficient Testing

- 6 Total Tests – changed top/bottom diverter designs, added insulation.
- Not all flags showed cooling at 80W, Wattage had to be adjusted to equilibrium.





Test # / Flag	BRLFO			BLLFO			BRLFI			BLLFI		
	Eq. Temp	Power	h	Eq. Temp	Power	h	Eq. Temp	Power	h	Eq. Temp	Power	h
T3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
T5	N/A	N/A	N/A	N/A	N/A	N/A	241.45	80	73.18	242.63	80	72.67
T6	250	72.32	62.97	250	80	69.66	237.23	80	75.05	237	80	75.15
T7	250	80	69.59	250	73.6	64.09	231.19	80	77.9	235.8	80	75.7
T8	250	80	69.6	250	75.4	65.66	236.8	80	75.24	218.6	80	84.58

Test # / Flag	BRUFO			BLUFO			BRUFI			BLUFI		
	Eq. Temp	Power	h	Eq. Temp	Power	h	Eq. Temp	Power	h	Eq. Temp	Power	h
T3	174.27	80	121.25	195.5	80	100.4	196.87	80	99.31	207.71	80	91.37
T4	211.23	80	89.06	209.54	80	90.15	209.86	80	89.95	212.97	80	87.96
T5	213.89	80	87.39	211.84	80	88.67	N/A	N/A	N/A	N/A	N/A	N/A
T6	212.62	80	88.18	210.4	80	89.59	250	67.58	58.85	250	64.5	56.16
T7	237.96	80	74.72	234.32	80	76.39	250	68.2	59.32	250	68.2	59.39
T8	172.26	80	123.67	175.33	80	120	250	66	57.47	249.65	80	69.8

$$\dot{Q} = hA(T_S - T_{Surr}) \qquad h = \frac{\dot{Q}}{A(T_S - T_{Surr})}$$

Fermilab

Updated Results

- Steady state temperatures @ 1MW appear to meet requirements of <100C.
- Hot spots are result of remaining conservative cooling coefficients. Further testing could reduce further but design goals are met.
- Final FEA planned for March finish.
- Final report to be released thereafter.