Fermilab

Particle Physics Division 12-01-01

Mechanical Department Engineering Note

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Title: Horn1 Stripline Air Velocity Measurements and Chase Mockup

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Key Words: ANU Stripline velocity chase horn1 cooling upgrades

Abstract/Summary: Testing done to determine cooling flow over the horn1 stripline. Air velocity was measured in a mockup of the NuMI chase in the MI-8 service building. In preparation for proposed ANU energy upgrades from 400kW to 700kW.

Applicable Codes:

Introduction

The proposed NOvA energy upgrades to the NuMI experiment (ANU) from 400kW to 700kW, place greater heat loads on the beamline components. Specifically, this test concerns the stripline on Horn1 in the Target chase. A mockup of the chase was constructed to study air flow characteristics over the stripline. Results from this test are intended to provide realistic data for input to an FEA simulation. This simulation is used to determine what, if any cooling upgrades are needed for the 700kW load conditions.

Conclusions

Although experimentation showed wide variation in flow over the stripline, it is shown to have relatively small effects on heat transfer between conductors. Fig. 5 shows for a 70% reduction in flow, there is less than a 20% reduction in the convection coefficient. Since internal convection is not heavily dependent on flow velocity, there is no benefit to increasing flow to these areas. However, external flow over the stripline has a much larger effect on heat transfer. Thus increased flow over exposed faces, such as the flag areas, will remove significantly more heat from the stripline. This has an added benefit of increased cooling to the hottest section of the stripline.

These results indicate it is valid to increase cooling coefficients in the FEA thermal model. A conservative value of 10 W/m^2K is suggested. Suggestions for cooling upgrades include increasing flow over the flag areas of the stripline (areas H thru M on Fig. 3). This may be accomplished either through mechanical redirection or a dedicated blower.

Figure 1. Picture from outside of the chase mockup, looking upstream at the Horn1 stripline.

Description

Structure The chase was assembled in the MI-8 service building. A Uni-Strut frame 40' long, 52" high and 48" wide was bolted to the floor just East of the enclosure access pit. Sheets of plywood and plexiglass covered the frame. The test chase was built around a prototype Horn1 and stripline. About 8' of open chase was downstream of the horn, another 20' upstream. The plexiglass down both downstream sides allowed visual monitoring while making measurements.

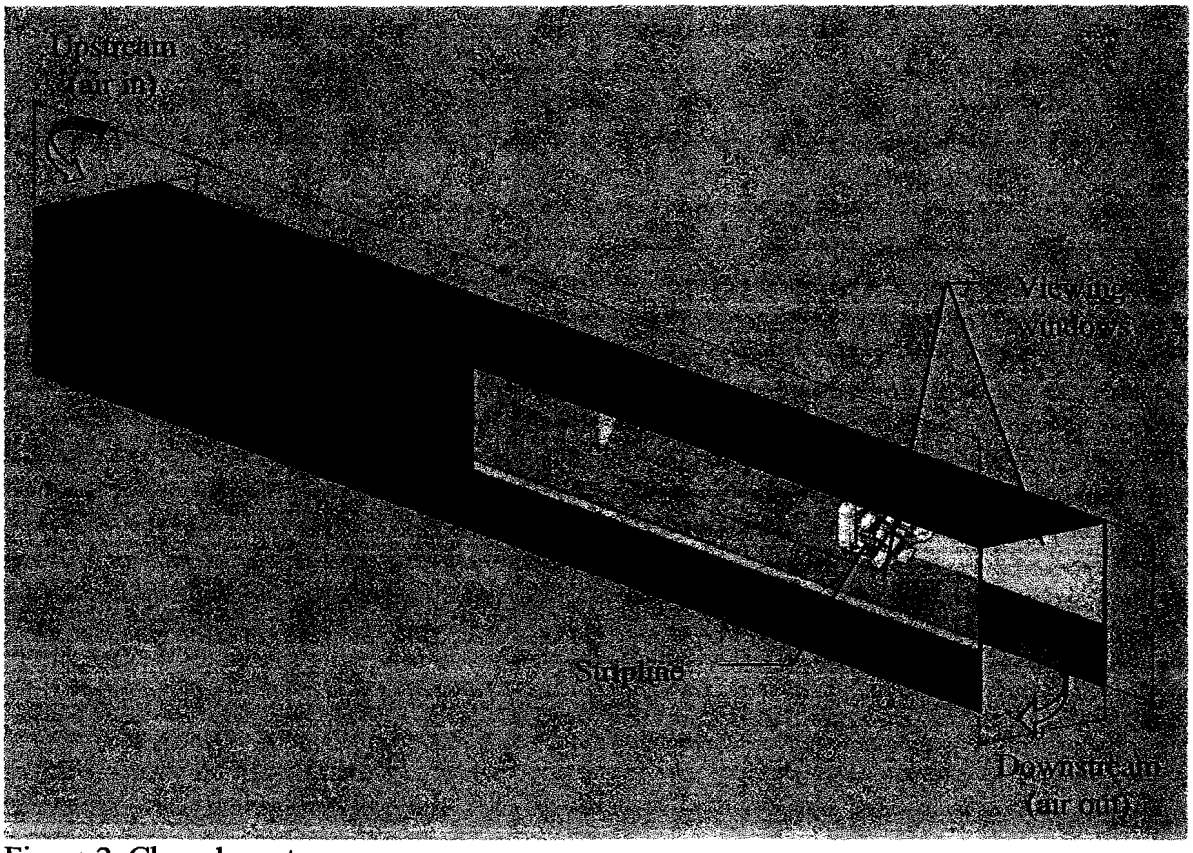

Figure 2. Chase layout.

Flow Conditions Calculations by Andy Stefanik indicate the volumetric flow rate in the Horn1 section of the chase to be around 20,000 cfm. The corresponding air velocity for the cross-section is near 25 mph. No blower units capable of producing this were available. Instead, a combination of fans and air circulators were used to create a range of velocities from 7-16 mph. For flow uniformity, air was pulled through rather than blown into the chase.

Measurement Holes drilled into the sides and top of the structure allowed instrumentation access. Additional holes were drilled immediately upstream and downstream of the horn/stripline and on the far upstream end of the chase to allow bulk flow measurement. Data was read using a hot wire anemometer. The hot wire probe was inserted through a hole, and aligned with the desired measurement location. Because the device only measures flow perpendicular to the probe, small adjustments to angle and position were

necessary to find the maximum, stable reading. Once an optimal orientation was found, readings were observed for approximately 15-30s. In some cases equilibrium was never reached, and readings would fluctuate continuously over a certain range. In these instances, a median value was selected.

Results

Velocity measurements were made on both the leading and trailing edges of the stripline and then averaged. In order to unify the measurements, all local measurements were divided by the maximum overall flow rate to generate a table of flow coefficients. Fig. 3 below shows locations of measurement on the stripline. Table 1 is a sample of coefficients derived from a max flow of 600 ft/min (7 mph). Fig. 4 is a plot comparing three data sets, and an extrapolated curve for 2200 ft/min (25 mph).

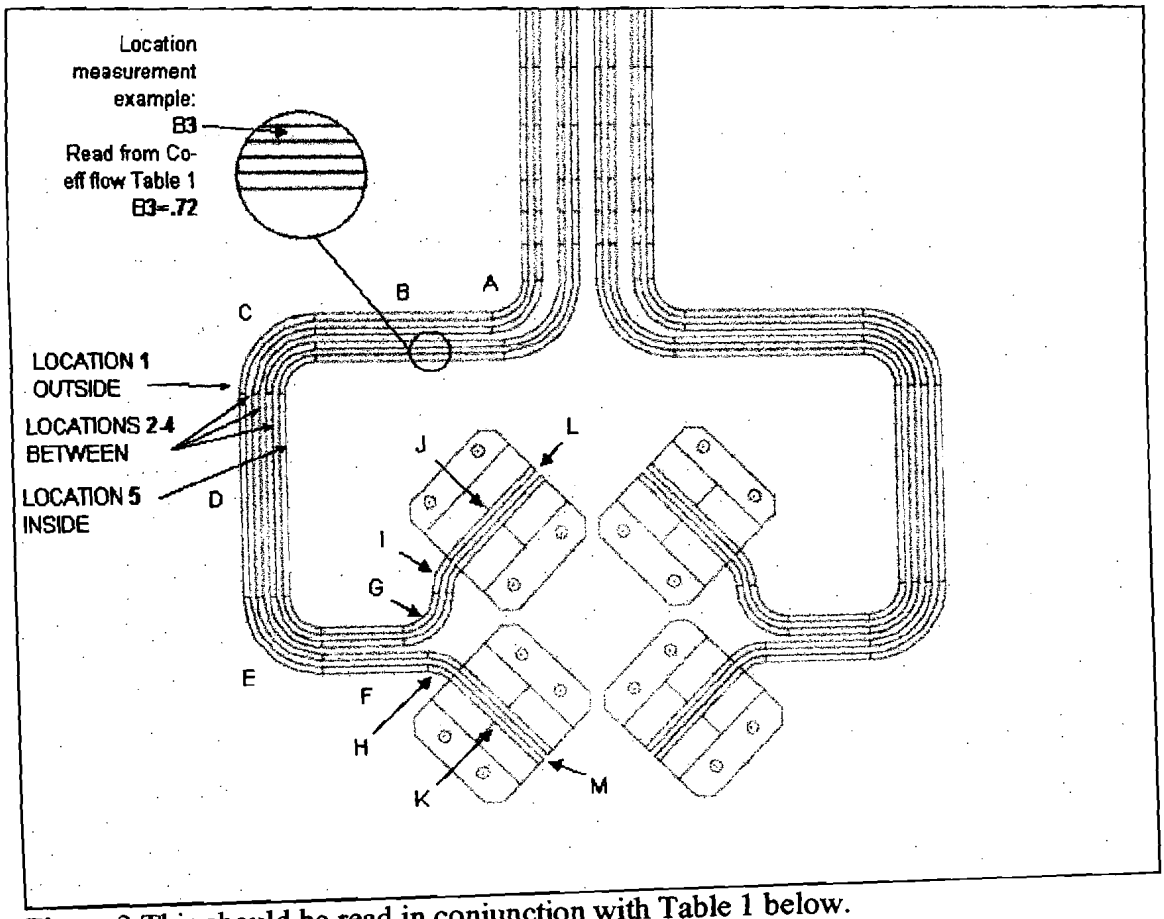

Figure 3 This should be read in conjunction with Table 1 below.

	1	2	3	4	5
A	0.88	0.48	0.67	0.39	0.33
B	0.95	0.77	0.72	0.83	0.75
C	0.88	0.78	0.77	0.85	0.78
D	1.02	0.84	0.74	0.78	1.01
E	0.96	0.93	0.97	0.78	0.93
F	0.78	0.74	0.74	0.73	0.88
G	0.33	0.50	0.57		
H	0.33	0.37	0.30		
I	0.25	0.31	0.48		
J	0.17	0.17	0.53		
K	0.37	0.17	0.17		
L	0.50	0.40	0.55		
M	0.36	0.28	0.35		

Table 1. **Flow coefficients** Measured maximum air velocity was 7 mph. Rows A-M correspond to locations *along the length* of the stripline (see Fig. 3 above). Columns 1-5 correspond to locations *adjacent* to the stripline conductors. Column 1 is outside the 1st conductor, column 2 is between the 1st and 2nd conductor, etc.

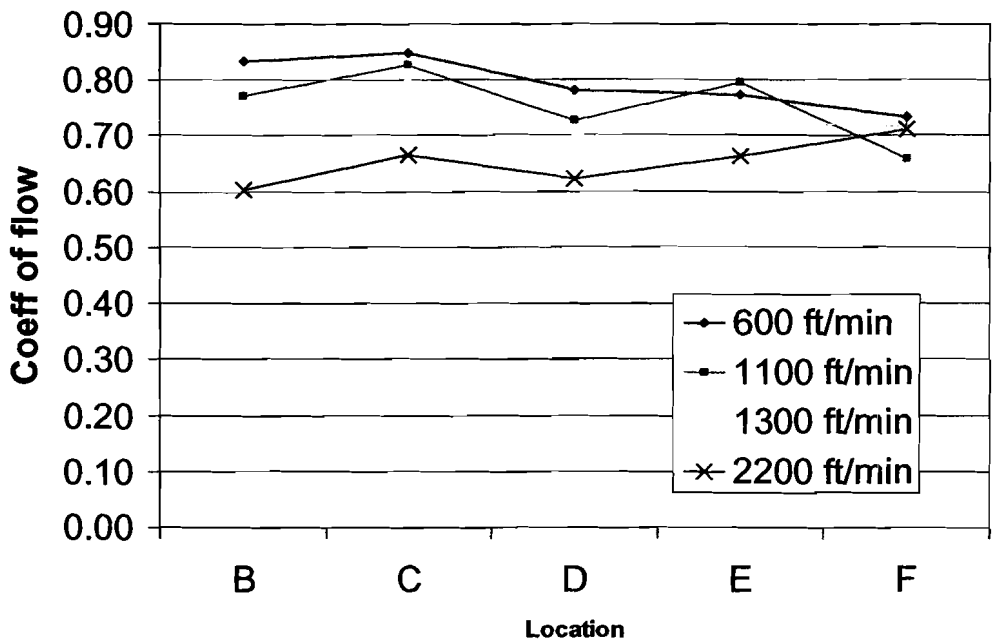

Figure 4. Plots of flow coefficients over the stripline. Corresponds to flow between 3rd and 4th conductors (column 4 of Table 1). Data points for 2200 ft/min are extrapolated from the other three cases.

Analysis

Below is a plot of heat transfer coefficients vs. air velocity. Fig. 5 shows curves for external flow and internal flow.

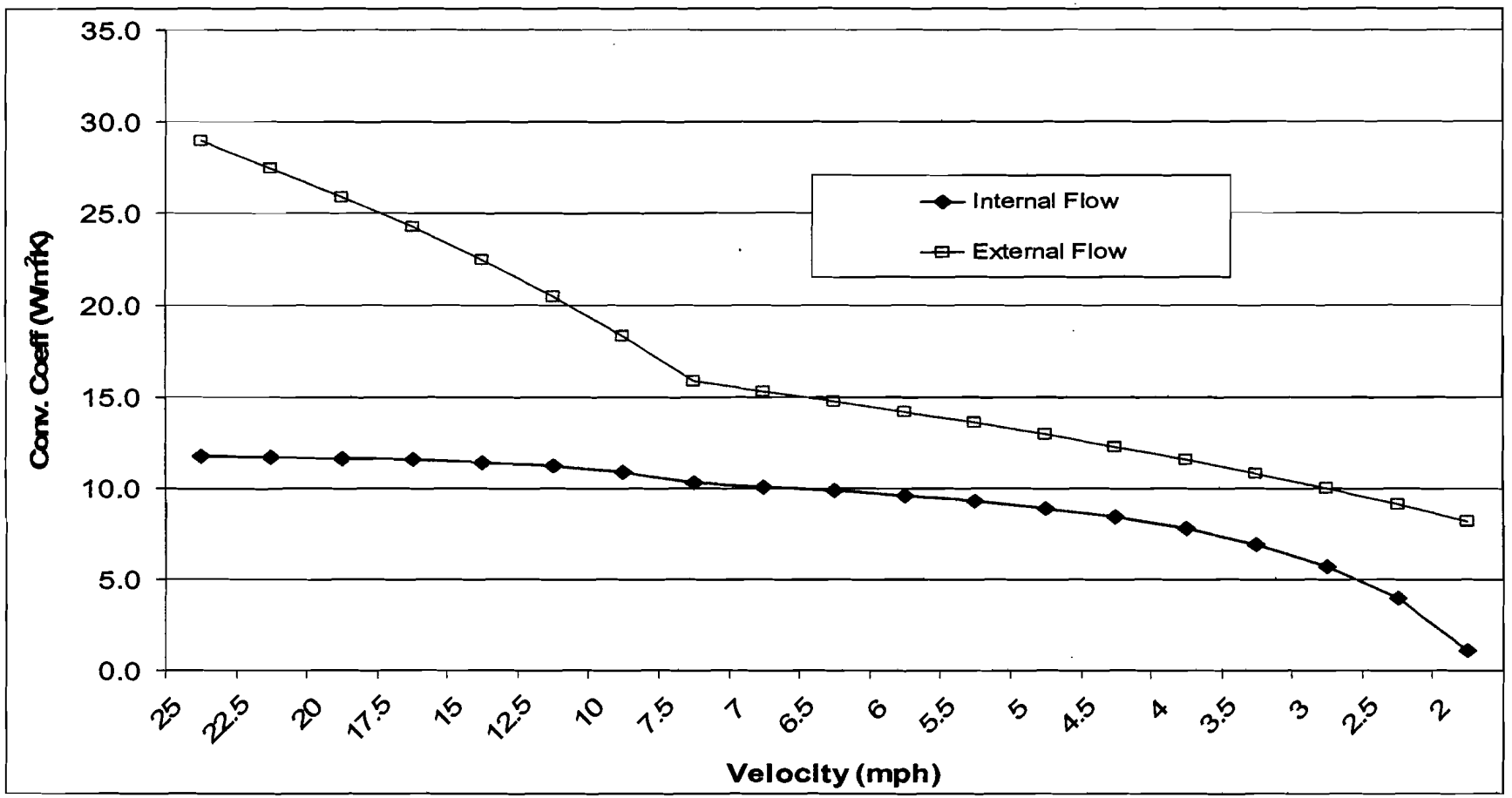

Figure 5. Convective heat transfer coefficients vs. air velocity. Values are for internal and external flow over stripline conductors in the chase. Sample calculations for the coefficients are included below.

Sample calculations for <u>external</u> flow heat transfer

(See example 7.1 (pg. 376) of *Intro. To Heat Transfer* 4th Ed by Incropera and DeWitt)

All air properties evaluated at 300K

$T := 300K$	Temperature
$P := 1atm$	Pressure
$\rho := 1.16\frac{kg}{m^3}$	Density
$\nu := 0.00001589\frac{m^2}{s}$	Kinematic viscosity
$k := .0263\frac{W}{m \cdot K}$	Thermal conductivity
$u := 11.2\frac{m}{s}$	Velocity (25 mph)
$Pr := .707$	Prandtl number
$L := .2m$	Conductor width
$Re := u \cdot \frac{L}{\nu}$	Reynolds number
$Re = 1.41 \times 10^5$	Flow is laminar, <5x10 5
$Nu := .664\sqrt{Re} \cdot \sqrt[3]{Pr}$	Nusselt number, average
$Nu = 222.094$	
$h := \frac{Nu \cdot k}{L}$	Heat transfer coefficient
$h = 29.205\frac{1}{m^2 K} W$	

Sample calculations for <u>internal</u> flow heat transfer (pg. 1)

(See table 8.1 and example 8.6 (pg. 465) of *Intro. To Heat Transfer* 4th Ed by Incropera and DeWitt)

All air properties evaluated at 300K

$T := 300K$	Temperature
$P := 1atm$	Pressure
$\rho := 1.16\frac{kg}{m^3}$	Density
$\nu := 0.00001589\frac{m^2}{s}$	Kinematic viscosity
$k := .0263\frac{W}{m \cdot K}$	Thermal conductivity
$u := 11.2\frac{m}{s}$	Velocity (25 mph)
$Pr := .707$	Prandtl number
$L := .2m$	Conductor width
$Ls := .3048m$	Section length
$t := .00953m$	Conductor spacing and thickness
$Pw := 2 \cdot Ls$	Wetted perimeter
$Pw = 0.61\,\mathrm{m}$	
$Ac := t \cdot Ls$	Cross sectional area
$Ac = 2.905 \times 10^{-3}\,\mathrm{m}^2$	
$Dh := \frac{4Ac}{Pw}$	Hydraulic diameter
$Dh = 0.019\,\mathrm{m}$	

Sample calculations for <u>internal</u> flow heat transfer (pg. 2)

$$Rei := \frac{u \cdot Dh}{\nu}$$ Reynolds number

$$Rei = 1.343 \times 10^{4}$$ Flow is fully turbulent, >10,000

$$f := \frac{96}{Rei}$$ Friction factor

$$f = 7.146 \times 10^{-3}$$

$$Nui := \left[\frac{\left[\frac{f}{8}(Rei - 1000) \cdot Pr \right]}{1 + 12.7 \cdot \sqrt{\frac{f}{8}} \cdot \left(Pr^{\frac{2}{3}} - 1 \right)} \right]$$

Nusselt number, correlation is valid for .5<Pr<2000 and 3000<Re<5x10 ^{6} See Eqn. 8.63 in Intro. to Ht. Transfer

$$Nui = 8.52$$

$$hi := \frac{Nui \cdot k}{Dh}$$ Heat transfer coefficient

$$hi = 11.756 \frac{1}{m^{2} K} W$$