AERO302

V for Venturi (F for Fan)

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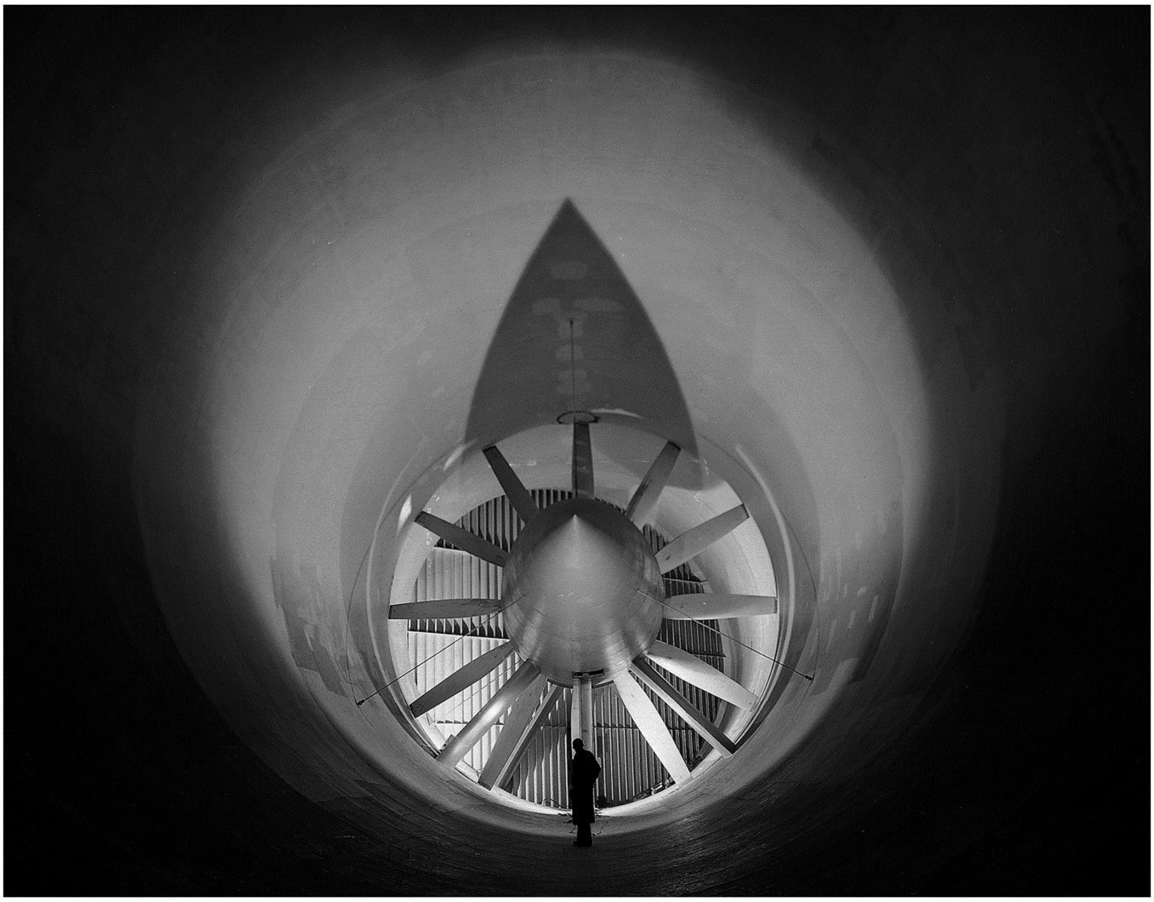

National Advisory Committee for Aeronautics
Aircraft Engine Research Laboratory

Objectives

This is your introduction to the Cal Poly Low Speed Wind Tunnel – we're here to ease you into wind tunnel testing in this first lab; eventually you'll become a comfortable and confident test engineer in the lab. At the start we'll help you plenty.

In this lab you will be able to:

- **Evaluate the velocity of air in the wind tunnel test section (and elsewhere) from pressure measurements**
- **Evaluate the "Venturi effect" from these pressure measurements, and determine whether your expectations from Bernoulli's equation are confirmed or otherwise**
- **Evaluate the fan and inlet/exit performance of the wind tunnel**
- **Contemplate sources of uncertainty and error in a basic wind tunnel test – in a subsequent lab we are going to explore in more detail what to do with this.**

Reminders

Treat the lab with respect, try to **leave it cleaner than you found it.**

Safety first – starting with your closed shoes every single time you're in the lab, but don't get complacent about anything and look out for each other in the lab.

Use your time effectively by preparing, by **being engaged and active during testing time**, taking heaps of notes, and getting to know your lab team.

This is a metric course! Talk in Newtons, meters per second, Pascals, and kilograms!

Ask lots of questions, and **think, think, think!**

Introduction

The Venturi Effect is a simple concept – fluid flows through a constricted section of a pipe…. when you think about it that's all a wind tunnel test section is… and the pressure reduces, with a corresponding increase in velocity. Pull in a lot of air, contract it, and get a fast speed in the test section. This is essentially the effect that the Bernoulli equation describes.

From your notes or some googling/reading, familiarize or re-familiarize yourself with **the Bernoulli equation, and more importantly, it's assumptions**. It's not going to be surprising to see the Venturi effect show up from measurements, but how good is Bernoulli as an assumption, and what does an engineer need to know about their test facility before they conduct more complex tests with a model aircraft or spacecraft (for instance, does the freestream velocity change from front of test section to the back? Is there an optimum fan rpm? What is the top speed/Reynolds number we can achieve?).

A fan is simply a mechanical device that uses revolving blades to produce flow rate and pressure rise. For a fan used in a flow system having a fixed system resistance, the volume flow rate should vary directly with the fan speed, the pressure rise varies with the square of the fan speed, and the power (horsepower or Wattage) should vary with the cube of the fan speed. **These are the so-called "fan laws".** If the fan speed is constant, the fan performance depends on the system resistance and hence the flow rate – in this lab we are going to see if we can reproduce something that resembles the fan laws, and we will also look at the influence of increased resistance in a pretty crude way… partially blocking the inlet with the whiteboard!!

Let's see if we can measure Bernoulli and the fan laws in action, and see how close the theory gets to reality.

Apparatus and Instrumentation

Your TA should have already explained how and where we are measuring pressure in the wind tunnel. Each pressure measurement station is equipped with a ring of static pressure ports (one on each side, one top, one bottom), all connected together to the "Scanivalve", which is a transducer bank. There is also a total pressure (pitot) probe at the inlet – why do we need that?

Have a look at the pressure lines – make sure to ask your TA which line is from which pressure station, if you are unsure. This is really important!

The fan RPM and power used is displayed on the control screen of the variable frequency drive (VFD) that controls the tunnel. You also have a vane anemometer or two to get quick measurements of velocity anywhere around the outside of the tunnel, and a magical tuft wand.

As long as you're not the first group, you have time to think about what you expect to see in the experiments (calculate Reynolds number, estimate the flow regime, work through some Bernoulli, research fan curves), and plan for how you will plot and interpret your data in and out of Matlab.

NOTE: Don't spend time sitting idle during the lab, time is tight! If you're not actively measuring something about the wind tunnel or the room or taking data, what else can you be doing? **Taking notes and pictures**? **Plotting the initial data to see if it's sensible**? Any problems you find now will allow you to re-run the test – that's not the case if you find them later.

NOTE: write down *all* the sources of error and uncertainty you can think of as you run tests, in the table at the end of this document, and whether you think they are significant or not (try to quantify where possible) – later this might help explain any unrealistic/wrong results. The pressure data you gather will allow you to look at the standard deviation in results – right now the goal is just to look at what are the main sources of error and what are the minor ones, and later we will do more with this information.

NOTE: agree with your group where the data and pictures and notes will be stored (e.g. Google Drive, Dropbox, OneDrive, etc.) and *make sure everyone has access and you've swapped contact details.*

What do you think you will need to know for a complete set of data for this experiment? What will you measure, and how will you measure it? What's important and what's not? **These are questions you want to discuss with your team and your teaching assistant BEFORE THE EXPERIMENT BEGINS.**

NOTE: Refer to your sketch of the wind tunnel and important dimensions/notes from week 1, and continue to annotate if necessary with new information.

Experimental Procedure

1) Review the relevant safety information if you have not already – specifically the safe working procedure for the wind tunnel that your group devised. You will follow this. Make sure you have all the measurements of tunnel dimensions you should need, from last week. You can check any missing dimensions later though, don't waste time on this now.

2) Take a reading of ambient conditions **at the start and end** of your lab. You can use any number of smartphone apps for a recent-model phone to get pressure and temperature, but we also have a digital station in the lab – ask your TA where that is if you're not sure.

   ASK YOURSELF: How accurate do you think the reading is?

   ASK YOURSELF: Why do we need to know ambient conditions? What info does this give us?

   ASK YOURSELF: Why do we need to take a reading at the end of the lab too?

3) Assign tasks to people – you will swap positions at some stage. One person will be operating the tunnel. One person will be monitoring the tunnel speed and pressure GUI live and calling out measurements. One person can be a gun on Matlab, calculating and plotting up results in near-real time as they come in. One person can be making notes on everything that's happening (especially if something changes, like a door opens, or a reading is re-taken, or there are any moments of confusion about what rpm it is, etc.), and checking that nothing unsafe is happening.

4) Make sure you know how the Scanivalve pressure measurement system is hooked up. Which port is total pressure? Which port is station 1, station 2, station 3, station 4, station 5? Are there any others hooked up? Don't be afraid to ask the TA what is going on!

   Ensure you know what the software is showing you (both for tunnel speed and measured pressures), and how to save it/output it. Don't worry, that's also what our teaching assistants are for, so **ask lots of questions** about this too!

5) Take a full set of pressure data with the tunnel not running (wind-off condition).

   ASK YOURSELF: Why do we need wind-off data?

   Setup the scanivalve interface to take data:

   Think of a file-naming convention for naming your data. Also match it up to any pictures you take or any other notes you take at the time. You don't want to be doing forensic work later to figure out what test was what and which port was giving which output.

   Input to the interface - some values for how many samples you want to take, and how you want the program to average for you. The TA will probably have some advice. Pick values that seem sensible right now, if you have time you can experiment more later.

   ASK YOURSELF: What's a "good" sampling rate in Hz? And what's a "good" sampling time?

6) Are you ready to start the tunnel? Run a **safety check** (doors, windows, etc. as per the **checklist by the Variable Frequency Drive and hopefully your Safe Working Procedure!**) with the TA and then start the wind tunnel with permission. If unsure, the assistant will help you run the tunnel and talk you through how that works, what settings mean what (rpm vs. speed, etc.).

7) Set wind tunnel to 100rpm. Start collecting your data after a settling period has passed. Data to collect:
    - Static pressure at each station in the wind tunnel (LabView, MATLAB)
    - Fan RPM (VFD)
    - Fan Power (VFD)
    - Inlet Velocity (Anemometer)
    - Outlet Velocity (Anemometer)

   ASK YOURSELF: Why have a settling period? How long is long enough, can you check something that would give you an indication?

   ASK YOURSELF: What's a good increment for ramping up tunnel speed from here? 100rpm? 200rpm? How much resolution do you need to get the information you're looking for?

   When using the handheld anemometers near the outlet be sure to follow the proper safety precautions; **never stand directly in the airflow, wear eye and hearing protection.**

8) You now have some data to save and start plotting. So do that. Call it out so that everyone knows "100rpm" or "measurement A" or whatever you want to call it.

9) Proceed to increment the rpm, let it settle, and repeat the last step. Do not exceed 1000rpm.

10) At your top RPM, take another reading. Or two. Or three. Repeatability is extremely important. Now or later – does the data show a large spread of results, or do you get the same thing each time?

11) Let's get repeat data all the way back down the rpm scale, OR, go back to zero and ramp up again. **NEVER, EVER**, trust an experimental result that you got once, even if your near-real-time plot looks quite nice. You don't know if it's a fluke until you have more information.

    If you have any testing time left in your slot, what other runs can you do? When a company pays for a block of tunnel time, they make the most of it - what else might you like to flesh out your data set? Some experimentation with averaging periods? Some more runs to get a better feel for the standard deviation? What is that standard deviation hinting at anyway? If the control room doors were open, is tunnel performance different with them closed?

If someone from the other group was measuring around or at the inlet, should you take another reading with them out the way? And so on. You'll never regret knowing too much about your test, but you'll always regret not knowing enough when you're analysing later.

Tunnel Pressure

Plot both measured pressure (as a coefficient of pressure), and calculated tunnel speed, from the data you've gathered, at each rpm. If you have repeatability data, overlay and look at the difference.

If you have standard deviation buried down in the raw data, plot the standard deviation for each measurement point. What does the standard deviation in your data set tell you about the flow conditions? Anything useful/physical?

ASK YOURSELF:

What is the test section q (dynamic pressure) at each tunnel speed, and why would it be more useful to run a repeat test at the same q compared to running it at the same speed?

How does your data compare to what Bernoulli would predict if you only had Station 1 to work with? Or station 1 and 2? (really, where does reality start to diverge from Bernoulli in a meaningful way, if it does, and why?).

What is the implication of any freestream speed change from the front of the test section to the rear, even though the cross-sectional area didn't change?

What are the mass and volume flow rates through the tunnel at each tested speed?

Does the low speed affect the Scanivalve's ability to read pressure properly at the inlet? If so, do you think this would affect your speed calculations much or not?

Why do we use a coefficient sometimes to describe data, rather than the raw number? Did something unusual happen (like a $C_P > 1$), and why?

How does the standard deviation compare to any other possible errors you noted in the table?

How close to ambient pressure do you expect the tunnel flow to be as it leaves the diffuser exhaust? What is the effect of this?

Fan Laws

Let's look at the fan laws.

Try plotting:

a. Volume Flow Rate Q (m^3/s) vs. n (rpm)

b. Δp_{fan} (Pa or kPa) vs. n^2 (rpm^2)

c. P_f (kW) vs. n^3

What trends do you see? Is it what you expected? How do you explain any wayward points or discrepancies? Also plot Δp_{fan} vs. Q, and vs P_f.

You may want to plot all these on one graph to facilitate comparison between curves, but choose the scales wisely so the lines aren't on top of each other and impossible to read.

ASK YOURSELF:

Did maximum fan efficiency, maximum power input, and maximum fan pressure rise all occur at about the same volume flow rate?

From your vane anemometer test, was the flow consistent when going into the inlet or did you think one side/area was favoured over the other? Same with the outlet – were there any stalled areas in the diffuser that you could tell, depending on the speed? What effect would any of these influences have, do you think?

What is your estimate from measurements for the mass flow of air through the wind tunnel vs. test section speed?

Without having any information about the thickness of the boundary layers going through the test section and fan sections, what kind of effect do you think they have on the fan performance?

Does the pressure rise infront of the fan, and the delta across the fan, correlate on a similar curve with flow rate and/or rpm, or are the rise and the delta behaving differently?

What could you do to get more performance out of the fan? What would be a theoretical and/or practical (physical or otherwise) limit for this for the Cal Poly tunnel?

The test section is a rectangular cross section. The diffuser is an octagonal cross section. What effect do you think this transition would have on the flow?

Useful Formulae

Bernoulli equation: $P_{Total} = P_{Stat} + q$

https://en.wikipedia.org/wiki/Bernoulli%27s_principle

- P_{Total} is the stagnation pressure at the point being evaluated (Pa)
- P_{Stat} is the static pressure at the point being evaluated (Pa)
- q is the dynamic pressure at the point being evaluated (Pa)

Dynamic Pressure: $q = \frac{1}{2}\varrho V^2$

https://en.wikipedia.org/wiki/Dynamic_pressure

- V is the mean velocity of the object relative to the fluid (m/s)
- ϱ is the density of the fluid (kg/m^3).

Coefficient of pressure: $C_P = p\text{-}p_\infty / \frac{1}{2}\varrho v^2$

http://en.wikipedia.org/wiki/Pressure_coefficient

- p is the static pressure at the point at which pressure coefficient is being evaluated (Pa)
- p_∞ is the static pressure in the freestream (Pa)
- ϱ is the density of the fluid (kg/m^3).
- v is the mean velocity of the object relative to the fluid (m/s)

Potential source of error	Known or estimated value ±	Relative influence high or low?

Try to fill this whole table.

Technical Memo guidelines

You will submit a technical memo on these experiments.

This does not need to be a long report. This *does* need to be a professional-standard report. Experiments are useless unless they're written up in a way that's understandable, and allows someone to reproduce both the experiment and the results. You can use the standard AIAA template if you like, for ready-made neatness, but delete the footer – this is a Cal Poly course, not an AIAA course! At the minimum, the report should feature:

A meaningful, concise **title with your names**, followed by an **Abstract** of < 150 words – summarize: what was done, how was it done, what did you find?

Nomenclature – comprehensive, and with units as well as symbols. Greek usually comes second to English letters and symbols.

Introduction – what's so interesting about the Venturi effect, fan performance, and wind tunnel flow in general? Find at least a couple of useful references you can cite when you write down some basics about the fluid dynamics (not just random websites please, look for reliable sources, be they a textbook or a technical report). Then what were the objectives of the experiments? What hypotheses were being tested?

Methodology – how was the experiment conducted? What equipment was used (what models? Instrumentation?), how accurate was it, what were the conditions of testing? Did anything go wrong that might affect the results? *In brief,* what was the testing procedure? <u>A really good schematic diagram is truly worth a thousand words</u>, photos can be helpful too sometimes – describe how the wind tunnel works, after all that's what you're really measuring. What equations did you use for the analysis? You don't need to put derivations in here, but maybe say why terms are important if they are.

Results and discussion – You have plenty to talk about, lots of data to support your discussion. However, this should be a concise, stand-alone section showing the results obtained. Clear plots, labelled axes, nice font size, use colour if you need. Look at some aerodynamic technical reports, what plots do you like the look of - the ones that are clean and clear, informative, and look professional? Aim for that. Plot a few curves on each graph to facilitate comparisons that you can then discuss, but don't overcrowd them with ALL THE DATA ON ALL THE PLOTS ALL THE TIME, that's incomprehensible to look at. You can keep including the "ideal" theory results for reference. Which results aren't "perfect" and why not? Why anything anything?

THE "WHY" IS JUST AS IMPORTANT AS THE "WHAT" (sometimes moreso) – think about how you answered the questions posed in the lab manual(s). Always *discuss* your findings once you've described them (don't just say THIS HAPPENED, tell me why it happened and what you think about it). Surprise yourself with an unexpected insight or a thought for future work in upcoming experiments – something you really want to find out now? Or a better procedure?

Finally, Conclusions – don't restate the abstract! But summarize what the findings were, the key outcomes.

MAX LENGTH: probably about 8 pages all in, maybe more? But don't shrink your plots or schematics just to make it all fit on 8, we need to be able to see them! 11pt font. Be detailed but concise, descriptive but not emotive! This is the challenge of any technical report. Don't exceed 10 pages.

Appendices: Any *useful* examples of raw data vs. post-processed, error estimations and calculations, any other data you feel is useful but not vital to the rest of the report. Don't just dump everything in here, but if there's something lengthy and interesting that is not key to the main body, then this is the place.