SIGMA EXPERT SOLUTIONS LLC

PORTABLE WIND TUNNEL FEASIBILITY

0001-005-WHT-02

Revision: 00

Disclaimer:

This is a white paper used to propose a concept and does not represent a design calculation. The results presented are based on careful consideration of inputs, review of calculation results, and comparison with other data, but independent check and review has not been performed. Use of this information as a basis for decision making should only be made after independent verification of calculations and independent review.

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1. INTRODUCTION

1.1. Background

Practical aerodynamic research performed in a wind tunnel is an important part of understanding aerodynamic forces and enhancing the learning experience. Unfortunately, typical wind tunnel installations require large, purpose-built facilities with high power requirements. The scale of these installations and their power requirements generally leads to high initial and operating costs. This means that few of these facilities are available for basic academic research and few students get any substantial time exploring aerodynamic experiments in a wind tunnel.

A wind tunnel that could be set up in a standard classroom environment and operate on standard wall power would mitigate some of the issues associated with limited access. To meet further requirements, the wind tunnel would have to be easy to operate, produce high quality results, and not require a large initial expenditure.

This white paper investigates the creation of a portable wind tunnel suitable for performing basic aerodynamic research in a classroom setting. It would operate on normal wall outlet power while providing a test area cross-section of reasonable size for most aerodynamic experiments. An emphasis placed on a design focused on boundary layer control and flow conditioning would maximize the usability of the wind tunnel. The use of readily available materials and construction methods would minimize cost.

This white paper outlines the vision for a prototype wind tunnel that could be quickly developed as a proof of concept leading to a design that could be widely implemented for educational and research purposes. After initial construction, extensive testing and subsequent design modifications would lead to development of a final version that could be used in a variety of educational environments.

1.2. Proposed Solution

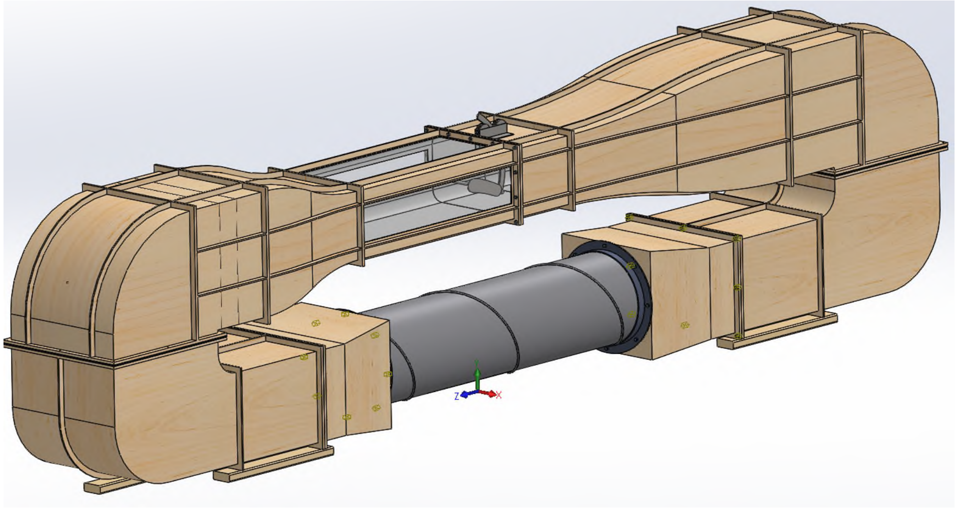
The proposed solution is a small closed-loop wind tunnel with a test section cross-section of 12 inches by 18 inches. The construction is mostly conventional plywood and spiral wound duct with motive force provided by high power electric model aircraft motors. A graphic of the proposed wind tunnel is shown at the end of this section. The critical aspects of the design are:

1. High portability – The design consists of five sections, each under eight feet long with a cross-section not exceeding 2ftx2ft. The sections would be lightweight enough to be easily man-portable and assembled without special equipment.
2. Compatible with a Classroom Environment – The proposed design is closed loop, which minimizes air disturbances and noise levels in the space where it is placed. Additionally, wall outlet power would be used as the power source, enabling its

use in most classrooms. A small footprint furthers its compatibility with the classroom environment.

3. High Quality Flow Conditions – The use of smooth contractions and expansions, large plenum volumes, the ability to easily incorporate flow straightening screens and vibration isolation provide the opportunity to tune the tunnel so that it can provide accurate and predictable results for a wide array of experiments. The ability to readily achieve a freestream velocity of 60 mph is considered necessary to have sufficient range of conditions for a variety of experiments.
4. Low cost – The design is optimized for the use of commercial off the shelf components and readily available materials that are easy to work. This results in a tunnel that can be constructed for less cost than a comparably sized tunnel using custom components and more exotic materials. The design would allow for the use of more exotic materials where there is an advantage, but the minimum cost version would provide sufficient capability for most educational settings.
5. Easily Upgraded – The modular design enables addition of enhancements, either as additional sections to the wind tunnel, or replacement of sections with more advanced designs. This prevents having to replace the entire tunnel for an upgrade to just one area as testing needs change. The simple construction of the wind tunnel makes special purpose modifications for instrumentation or model mounting easy to implement.

The focus for this white paper is to determine the feasibility of an initial prototype for a portable wind tunnel that can demonstrate the ability to provide high quality test conditions for a low cost. The intention would be to use this prototype as a stepping stone to a more advanced variant that would be based on testing performed on the prototype. The variant would address aspects of flow conditioning, tunnel usability, instrumentation, construction methods, boundary layer control, and power requirements that are best determined by experimentation rather than extensive analysis. Analysis and evaluations are scoping in nature to determine whether construction of the prototype tunnel is warranted, but do not guarantee performance.



1.3. Results and Conclusions

Based on scoping analysis, the proposed solution would be capable of providing a freestream velocity of at least 60 mph (5280 fpm) with a power consumption of approximately 2400W. Using a pair of regularly available model aircraft motors (shown highlighted in Appendix C) the ability to meet the required 60 mph freestream velocity could be met with only one motor, ensuring sufficient margin. With standard available batteries, a run time at this power would be approximately 4 - 8 minutes with no external power. Provision of wall power with concurrent charging would increase this run time. At a more moderate freestream velocity of 30 mph (2640 fpm) the required power would be approximately 300W which could be readily supplied by most standard outlets.

The resulting design can be easily constructed with standard materials and proven techniques. The resulting structure would be easy to assemble, lightweight, and sufficiently rigid to support aerodynamic testing requirements.

Best practices in terms of high contraction ratio prior to the test section, large, low velocity plenums, and a slowly diverging expansion section should result in relatively large useful area of well-conditioned flow. The ability to incorporate flow screens and readily change them for the test conditions enhances this potential. Due to the design, boundary layer control by providing wall suction in the test section could be easily incorporated to further increase the effective cross-sectional area of the test section.

2. EVALUATION OF SOLUTION

2.1. Method of Evaluation

A scoping analysis is used to show the power requirements of the prototype tunnel to determine the feasibility of sourcing motors and operating them continuously. Experience and expert judgement is applied to evaluate the construction method and materials for the tunnel. Best practices are used to maximize the quality of the airflow. No detailed analysis or simulations are performed to evaluate the prototype tunnel, as performance of these types of evaluations would be more time consuming, costly, and less accurate than construction of a prototype tunnel and experimentation.

2.2. Power Requirements

2.2.1. Method of Analysis

To determine the power requirements for the tunnel, the total pressure drop due to wall friction must be overcome by the fan system to maintain steady flow. The tunnel is essentially a closed duct, and therefore the methods established in the ASHRAE handbook can be used to determine the pressure drop.

Appendix A, shows the loss calculation for each section of the wind tunnel in the tables a various freestream velocities. For purposes of calculation, the wind tunnel was separated into 10 separate hydraulic sections organized by following the flow for air. The first section is the test section area with constant cross-section. This is followed by the expansion (diffuser), and a turn to the bottom section. The bottom section of the wind tunnel is modeled as the turn towards the power module, entrance to the tube housing the fans, exit from the tube, and the turn towards the top module. The top section is completed by the turn towards the test section and the contraction. Two flow straightening screens are added between the final turn and the contraction to simulate future flow straightening devices that may be needed.

The correlations used from Chapter 35 of the ASHRAE handbook (2004 edition) for fittings are noted in the table under the “Notes” column. For straight sections, a standard pressure loss calculation is performed. In all cases, a wall roughness equivalent to relatively rough fibrous glass duct is used. This is a conservative approximation, as the achievable wall smoothness should be well below what is typical for this type of ductwork with standard finishing methods. For the screens, an open area of 80% was modeled and is considered conservative.

Average atmospheric conditions are used as inputs as well as volumetric airflow and local loss coefficient when determining the pressure drop for each section. Appendix A shows the resulting tables at three different test section freestream velocities. By adding the individual pressure losses, the total system pressure loss can be calculated to determine the amount of energy input required by the fan system. Typical efficiencies for propellers and electrical motors are used to determine the total electrical input power required.

2.2.2. Assumptions and Simplifications

The results of this method provide a good understanding of the power requirements, but only provide a rough indication on anticipated actual operation. The purpose is to determine the feasibility of providing sufficient power to achieve the velocity objectives. There are many simplifications and assumptions which may result in different operating characteristics than analyzed. Some of the most critical assumptions and simplifications are:

- The method of flow straightening has not been established. Significantly more pressure loss may be caused by the method of straightening than accounted for after testing has been completed.
- Pressure drop due to models has not been added. Its value will vary significantly based on the type of model and instrumentation in the tunnel, but it is not expected to be significant relative to the ductwork and flow straightening losses.
- Typical values for propellers and electrical motor efficiencies were used. Higher efficiencies may be experienced in some flow conditions, but in other conditions lower efficiency may result.
- The seams between the ductwork sections have not been considered in the pressure drop calculation. Most seams would be fairly flush using the flanged construction method and within the thickness of the boundary layer, minimizing their impact. Misaligned sections, or manufacturing variances could create obstables that cause a significant change in the pressure drop calculation.
- The effect of fittings such as windows, instruments, etc. has not been calculated. These losses are best developed during testing.
- The inside corners of the ductwork are filleted, which slightly reduces the cross-sectional area and increases flow velocity. This may have some effect, especially in the test section where the area is smaller, but the impact to effective hydraulic diameter is considered minimal.

2.2.3. Results

The scoping analysis shows that approximately 2500W of electrical power are required to operate at 60 mph freestream velocity in the test section. Only 300W is required at 30 mph. A maximum achievable airspeed of approximately 75 mph is possible with the specified motors in the current design, which would require nearly 5000W of electrical power.

2.3. Construction Methods

2.3.1. Overview

The method of construction is essentially composite wood products (plywood) supported by an external frame. Construction methods typical of plywood boat hulls would be used as they are well understood and produce rigid, airtight (and water tight) structures capable of withstanding high pressure. The interior edges are filleted and sealed with epoxy filler, sanded smooth, and painted.

The motor section is constructed using standard spiral wound duct for its pressure boundary combined with custom transition pieces made of the same wood materials used for the rest of the shell.

Areas where additional re-enforcement is needed, such as: flanges, instrumentation mounting points, and windows, additional layers of plywood layers are added through lamination to increased stiffness without adding significant weight to the overall assembly.

2.3.2. Assembly

The top and bottom sections are assembled with bolts in installed flanges that are part of the external space frame. At each flange connection, rubber or foam gaskets are used to provide a pressure seal and adjust for any variability in the flange face. This method of assembly has the advantage of familiarity, simplicity, and assembly with basic hand tools. The top section rests on the bottom section and is held in place with locating pins and gravity. A vibration absorbing gasket is placed between the top and bottom sub-assemblies at the inlet and outlet plenums. This serves to isolation motor vibrations from the test section.

The entire weight of the prototype tunnel would be supported by the bottom section flanges in this configuration. Alternative support methods could be incorporated after initial construction to improve usability, stability, and vibration isolation.

2.3.3. Wood Shell construction

The shell of the tunnel that comprises the pressure boundary is made of thin plywood or similar wood-based composite. The plywood used would be either a 1/8 inch birch plywood or a high grade luan of similar thickness. Both have been successfully used to make boat hulls with similar or tighter curvature than required for the design. Where the panels meet at the edges, “stitch and glue” or internal chines are used to ensure a strong edge seam.

To maintain shape of the shell, external frame members constructed of thicker plywood are installed. The plywood frame creates a space frame to support the shell at key locations of high pressure, high structural stress, or where shape control is critical. The frame may be assembled before the shell to serve as guide when forming the pressure boundary panels.

After initial construction, the inside corners of the tunnel are faired and sealed with an epoxy and microsphere filler or similar. After sanding, the entire interior would be coated in a body filling compound to fill in any imperfections or screw holes. After coating, sanding of the interior and painting with a high durability paint completes the interior surface. The exterior of the tunnel is painted with traditional methods or left unfinished.

This method of construction results in a lightweight and stiff structure that can be quickly manufactured. Appendix B shows a preliminary drawing of the completed tunnel and identifies the different sections. The overall weight of the assembly is also calculated in this drawing.

2.3.4. Motor Section Construction

The motor section pressure boundary consists of a section of spiral wound duct and transitions to match flanges in the plywood section of the tunnel. The transitions are constructed out of plywood and filler material, as outlined in the section above. The transitions bolt directly to the flanges of the spiral wound duct. A standard size spiral wound duct is used as because of its consistent circular cross-section, stiffness, availability, and ability to easily mount motors and provide entrances for cabling without compromising structural integrity.

Internal to the duct, custom motor mounts are required for mounting of the electric motors. These are constructed with any means available including plywood, 3D printing, or machining. The motor selected during design completion will determine the best construction method.

2.3.5. Connection Points

Connections between sections are with flanges. Flanges are integral to the shell space frame and made of similar materials. Within the bottom and top sub-sections, a flexible rubber gasket of medium resilience is used between the flanges to create a seal, and standard bolting between the two flanges provides a strong connection requiring only basic hand tools.

There is no “hard” connection between the top and bottom portions of the tunnel. The bottom part of the tunnel is set in place and supported by the floor. A vibration absorbing gasket is placed on the upward facing flanges, and the top portion of the tunnel is lifted in place. Simple locating pins on the bottom subassembly flanges ensure alignment. This type of connection allows for easy access to flow conditioning devices during tunnel testing and vibration isolation between the motor section and the test section.

2.3.6. Tunnel Support

The initial prototype tunnel is self-supporting on level ground. The flanges on the bottom sub-section of the tunnel lie within the same plane and support the entire weight of the tunnel. With all support provided by the bottom flanges, some means of shimming the flanges to adjust for floors that are not completely flat or variability in assembly construction is needed. The figure at the top of this white paper shows this method. Other methods of shimming may be incorporated based on specific locations.

During testing, integration of additional support may be determined as appropriate and can be easily incorporated to relieve the stress on these flanges, increase isolation between the top and bottom section, and increase stability of the assembly. If separate support is desired for the top section, simple support legs connected to the flanges between the turns and the straight sections would provide a means of relieving weight from the bottom subassembly sections, increasing vibration isolation, and allowing for increased control over assembly leveling. This would increase complexity but may have the added benefit of increasing assembly stability during operation.

2.4. Airflow Quality

There are many variables that can affect the quality of airflow through the test section. The purpose of the protype tunnel is to provide a test platform for exploring different strategies that optimize airflow quality. The prototype design incorporates features that assist with airflow quality and the ability to test different strategies.

2.4.1. Test Section

The test section has a length that is 4 feet long with a flange at the 3 foot mark. The intention is for most models to be just in front of the flange, providing the longest possible straight section prior to the flange transition. The location of the flange transition delays the potential turbulence, but also provides an opportunity to integrate active boundary layer control at this flange where the boundary layer is anticipated to be thickest. Sections on future testing address this in more detail.

The integration of the viewing windows will pose a challenge in ensuring they do not upset flow. Detailed design work on their installation is needed to minimize the impact on flow quality.

2.4.2. Diffuser and Contraction Sections

The diffuser section is as long as possible with a gentle increase in cross-section to avoid flow separation. This will maximize tunnel efficiency and improve upstream flow quality.

The contraction section provides a rapid contraction after flow straightening with a smooth exit. This design is to compress the boundary layer prior to entry into the test section and create parallel streamlines downstream from the flow screens. The opportunity to use static pressure taps along the contraction as a means of determining tunnel air speed is also afforded by this feature and will be discussed in the testing section. Note that the contraction section is integrated with the test section so there is no seam between these two portions of the tunnel.

2.4.3. Inlet and Outlet Plenums

The plenums at the inlet and outlet are as large as possible to create a static, high pressure condition that enables pressure recovery. The plenums are defined by the volume within both the top and bottom turns combined.

The inlet plenum allows for static pressure recovery from the motor section, and creation of a large static pressure area upstream of the contraction section that can be applied to a flow screen. The application of lower speed, high static pressure air volume to a flow screen. Easy access to the plenum by lifting off of the top section provides an ideal platform for testing various flow conditioning schemes, including turning vanes, different combinations of flow screens, honeycomb flow straighteners, etc. The design is specifically based on the ability to experiment and develop the best flow conditioning strategy for the final version of the tunnel.

The outlet plenum provides pressure recovery from the diffuser prior to entry into the motor section. The primary purpose is to improve wind tunnel efficiency and minimize power requirements and noise. Additional features may be incorporated during testing to enhance these features such as turning vanes, and insulation.

2.4.4. Motor Section

The motor section primarily consists of a duct with circular cross-section containing one or more motor mounted propellers. The reference design has two motor/propeller assemblies in series. The internal diameter of the duct closely matches the diameter of the propellers to minimize tip losses from the propeller and improve efficiency. The concept of two series propellers affords the ability to only incur half of the pressure increase at each propeller which will balance motor load and minimize the potential for separation. An additional advantage is the ability to tune out any resonant frequencies which may be encountered during testing by individually adjusting the two motors. By operating the two motors independently, these frequencies could be avoided while still operating the tunnel through the whole flow regime.

3. FUTURE WORK

To fully develop the wind tunnel concept, prototype construction and testing must be performed. The following section provides some insight into the vision for how the proposed prototype tunnel will lead to a final version of the wind tunnel that can be used as an educational tool in many different facilities.

3.1. Complete Prototype Design Work

Most of the prototype design is complete, but details of construction must be finalized prior to moving into construction. The following items are still open:

- Thickness of plywood – The initial concept uses 1/8 inch (or 3 mm) plywood for the shell. Alternatively, there are thicker, flexible plywoods available as well as high quality luans that provide a cheaper alternative. Thicker plywood could be used for flat areas to improve stiffness as well. For the flanges and external frame members, the thickness has not been determined and will be based on calculation of the necessary strength to resist structural forces and pressure forces. A final determination on plywood materials would be based on availability, cost, ease of use, and required strength.
- Location of external frame members – The preliminary design considered considered where areas of high stress areas are expected and where frame location would simplify the construction process. Additional review of the exterior frame is required to ensure that all high stress areas are reinforced, and construction of the frame is feasible.
- Edge seam construction – The manner of connecting pressure boundary panels together at the edges must be determined. Two common methods were discussed above: stitch and glue and internal chines. The decision on which to is preferable will be based on considering the easiest construction method for this assembly.
- Bolted Assembly – Connection with flange bolts has been determined, but the sizing of the bolts still needs to be calculated, as well as the number and spacing of bolt holes. The gasket material will also need to be determined.
- Vibration Isolation Assembly – A preliminary concept of a thick, soft EPDM gasket with a few locating pins has been developed. Further investigation on the appropriate gasket stiffness and design of locating pins will have to be performed.
- Motor Mounting – A motor and propeller combination has been selected as part of the initial design based on readily available information (Appendix C), but a more thorough investigation on motor options should be performed coupled with an appropriate propeller selection. The result will have to have a custom motor mount designed that can be bolted to the spiral wound duct.
- Viewing window design – The ability to remove the viewing windows for model access is critical to the design. This requires a method of mounting the viewing windows that minimizes its impact on airflow as they are in the test section of the tunnel. Eventually an

active boundary layer control concept may be integrated into these windows, but for the initial prototype, a design that provides the smallest seam is required.
- Motor Control and Power System Design – The power requirements are known, but a motor controllers and batteries will be required for tunnel operation. These can be all off-the-shelf products, but must be specified to complete the prototype tunnel.

3.2. Prototype Construction

Prototype construction would be performed to match the drawings with the most basic features. No additional features such as mounting for instrumentation, additional supports, flow screens, etc. will be provided. The exterior will likely remain unfinished to allow for mounting of external items as testing is performed.

3.3. Test Planning

Prior to initiating testing with the prototype tunnel, a test plan must be established. The objectives for the tunnel must be determined. The test plan must include adding enhancements to the tunnel as well as necessary instrumentation. This will include documenting what modifications will be made as testing progresses.

3.4. Tunnel Testing

Tunnel testing is the final stage for the described tunnel. At a minimum tunnel testing should cover three stages:

- Determine Validity of Initial Design
- Experiment with flow quality improvement
- Determine instrumentation and model integration

3.4.1. Determine Validity of Initial Design

During initial commissioning, basic function of the tunnel must be ensured prior to moving on to more complex testing. This is to ensure that there are no critical errors in the design that preclude completion of the testing regime. The areas of concern are:

- Structural Integrity – Is the tunnel structure strong enough for the forces encountered? Initial startup should monitor movement of the pressure boundary, indications of high stress locations, and places where reinforcement would benefit downstream testing.
- Power Requirement – Does the installed flow module provide the necessary power to test the tunnel? This test would require operation of the motors at their maximum safe capability to determine the maximum airspeed and power draw in the “raw” condition. The results should consider integration of future flow straightening devices and models that will increase flow resistance.
- Vibrations – Are there flow regimes or operating characteristics that cause high vibrations? These will challenge the ability to isolate vibrations from the test section, masking testing

performed for flow quality. Strategies for minimizing vibration must be developed prior to entering the next phase of testing.

After this phase of initial commissioning, it is anticipated that some minor changes to the tunnel may be required. The next stage of testing would commence after the necessary improvements are complete.

3.4.2. Experiment with Flow Quality Improvement

Flow quality improvement is based on the ability to control velocity variability laterally and longitudinally in the test section. The former is primarily concerned with equalizing the flow across the cross-section of the test section and the latter is concerned with controlling the growth of the boundary layer and overall turbulence. In all cases, instrumentation needs to be developed to measure the flow quality before and after solutions are implemented. Some combination of instrumentation that can measure turbulence, flow direction, velocity variability, and boundary layer thickness will be specified and integrated into the tunnel.

For control of cross-sectional velocity variability, typically screens are implemented which create a relatively high pressure drop section that more evenly distributes flow across the downstream side of the screen. Having the incoming air impact evenly across the screen would further decrease variability, and the use of turning vanes is a typical approach. It is anticipated that at least one screen will be required prior to entrance to the test section. Experimentation with screen sizes, number of screens, and screen placement will be required to determine an optimal solution. Further investigation on whether turning vanes provide value should be performed.

For longitudinal velocity variability, there are essentially two factors under consideration. The first is the effective “shrinking” of the cross-section due to boundary layer growth in the test section. The second is the introduction of internal turbulence in the freestream that makes testing inconsistent. Boundary layer growth control could be addressed by active boundary layer control, such as taking suction at specific stations at the test section, or passive approaches such as improving wall conditions, including the method of window attachment. Turbulence in the freestream would most likely be cause by the use of screens close enough to the test section that freestream velocities have not stabilized. Use of a flow straightener in conjunction with the screen may be needed if unacceptable turbulence is encountered.

3.4.3. Determine Instrument and Model Integration

Based on the testing provided in the previous stages, enough information will have been generated to determine the best types of instrumentation, and how to structurally mount the instrumentation and model mounting systems. A general type model and instrumentation suite should be optimized during this testing. Shown in the figures for this white paper is a basic airfoil experiment attached to a generic test stand that penetrates the diffuser section and allows for angle of attack adjustment. The test stand can be outfitted with a force balance. Airspeed velocity could be determined from the test stand probe or using static pressure ports in the converging section. The intention is to develop an instrument and model set that could be immediately valuable for classroom instruction.

3.5. Finalize Design and the Future

Based on testing, design updates will be required. Modifications made during testing will be integrated into the design, and feedback from usability aspects integrated. The resulting updated design would be the basis for creating an educational tool that could be used across a wide spectrum of facilities and provide hands-on experience with wind tunnel testing. Note that the prototype tunnel is relatively small for more complex testing, but the lessons learned and the design approach can be readily scaled up for a larger tunnel for more complex testing and larger models.

A. PRESSURE DROP AND POWER CALCULATIONS

A.1. Overview

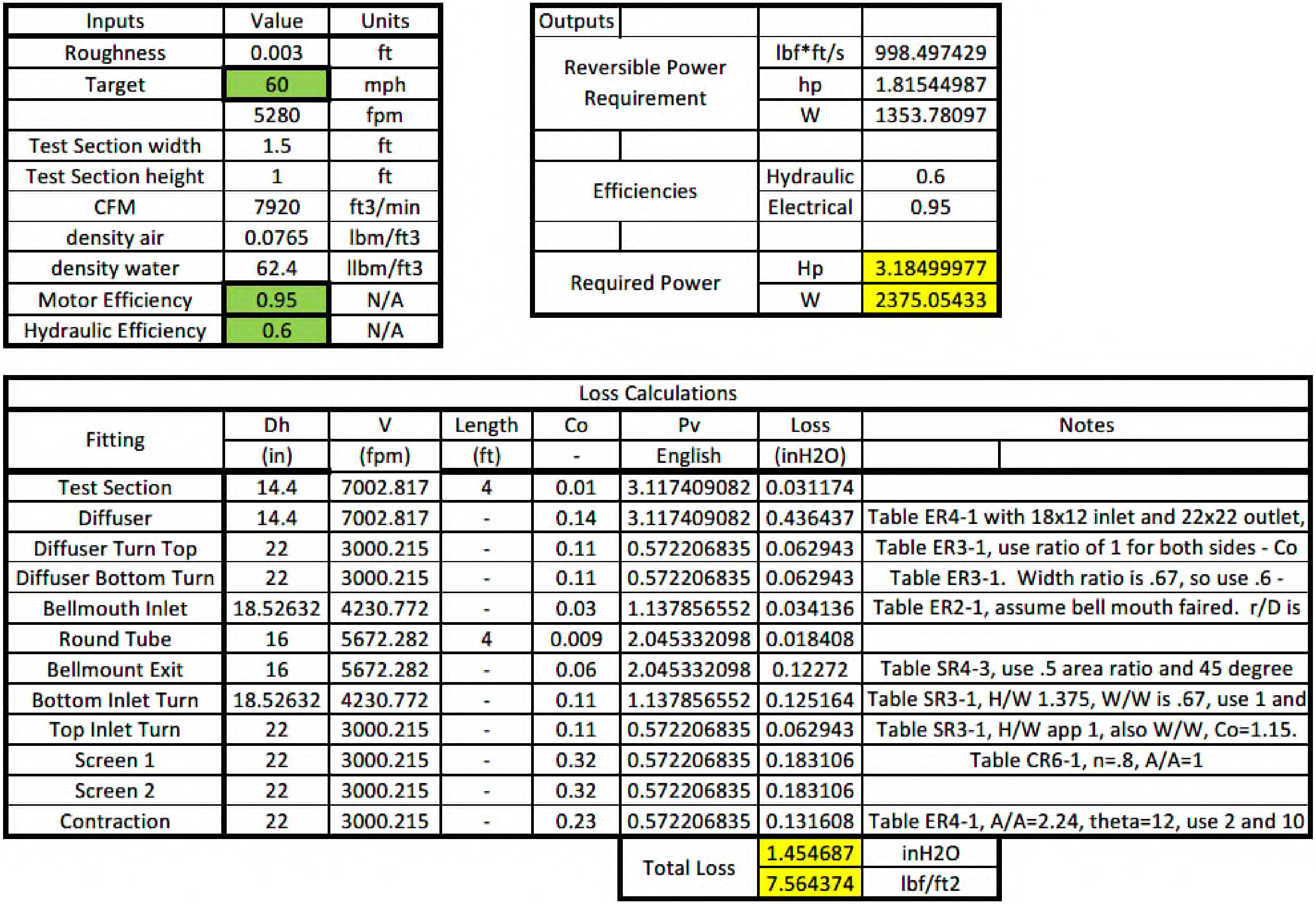
The following sheets show the result of a Microsoft Excel workbook calculation that determines the pressure drop and power requirement for the reference wind tunnel at various test section freestream velocities. Results for three different freestream velocities are shown in the following sheets.

Inputs	Value	Units
Roughness	0.003	ft
Target	30	mph
	2640	fpm
Test Section width	1.5	ft
Test Section height	1	ft
CFM	3960	ft3/min
density air	0.0765	lbm/ft3
density water	62.4	llbm/ft3
Motor Efficiency	0.95	N/A
Hydraulic Efficiency	0.6	N/A

Outputs		
Reversible Power Requirement	lbf*ft/s	124.812179
	hp	0.22693123
	W	169.222621
Efficiencies	Hydraulic	0.6
	Electrical	0.95
Required Power	Hp	0.39812497
	W	296.881791

Loss Calculations							
Fitting	Dh	V	Length	Co	Pv	Loss	Notes
	(in)	(fpm)	(ft)	-	English	(inH2O)	
Test Section	14.4	3501.409	4	0.01	0.77935227	0.007794	
Diffuser	14.4	3501.409	-	0.14	0.77935227	0.109109	Table ER4-1 with 18x12 inlet and 22x22 outlet,
Diffuser Turn Top	22	1500.108	-	0.11	0.143051709	0.015736	Table ER3-1, use ratio of 1 for both sides - Co
Diffuser Bottom Turn	22	1500.108	-	0.11	0.143051709	0.015736	Table ER3-1. Width ratio is .67, so use .6 -
Bellmouth Inlet	18.52632	2115.386	-	0.03	0.284464138	0.008534	Table ER2-1, assume bell mouth faired. r/D is
Round Tube	16	2836.141	4	0.009	0.511333025	0.004602	
Bellmount Exit	16	2836.141	-	0.06	0.511333025	0.03068	Table SR4-3, use .5 area ratio and 45 degree
Bottom Inlet Turn	18.52632	2115.386	-	0.11	0.284464138	0.031291	Table SR3-1, H/W 1.375, W/W is .67, use 1 and
Top Inlet Turn	22	1500.108	-	0.11	0.143051709	0.015736	Table SR3-1, H/W app 1, also W/W, Co=1.15.
Screen 1	22	1500.108	-	0.32	0.143051709	0.045777	Table CR6-1, n=.8, A/A=1
Screen 2	22	1500.108	-	0.32	0.143051709	0.045777	
Contraction	22	1500.108	-	0.23	0.143051709	0.032902	Table ER4-1, A/A=2.24, theta=12, use 2 and 10

Total Loss	0.363672	inH2O
	1.891094	lbf/ft2



Inputs	Value	Units
Roughness	0.003	ft
Target	60	mph
	5280	fpm
Test Section width	1.5	ft
Test Section height	1	ft
CFM	7920	ft3/min
density air	0.0765	lbm/ft3
density water	62.4	llbm/ft3
Motor Efficiency	0.95	N/A
Hydraulic Efficiency	0.6	N/A

Outputs			
Reversible Power Requirement		lbf*ft/s	998.497429
		hp	1.81544987
		W	1353.78097
Efficiencies		Hydraulic	0.6
		Electrical	0.95
Required Power		Hp	3.18499977
		W	2375.05433

Loss Calculations

Fitting	Dh (in)	V (fpm)	Length (ft)	Co -	Pv English	Loss (inH2O)	Notes
Test Section	14.4	7002.817	4	0.01	3.117409082	0.031174	
Diffuser	14.4	7002.817	-	0.14	3.117409082	0.436437	Table ER4-1 with 18x12 inlet and 22x22 outlet,
Diffuser Turn Top	22	3000.215	-	0.11	0.572206835	0.062943	Table ER3-1, use ratio of 1 for both sides - Co
Diffuser Bottom Turn	22	3000.215	-	0.11	0.572206835	0.062943	Table ER3-1. Width ratio is .67, so use .6 -
Bellmouth Inlet	18.52632	4230.772	-	0.03	1.137856552	0.034136	Table ER2-1, assume bell mouth faired. r/D is
Round Tube	16	5672.282	4	0.009	2.045332098	0.018408	
Bellmount Exit	16	5672.282	-	0.06	2.045332098	0.12272	Table SR4-3, use .5 area ratio and 45 degree
Bottom Inlet Turn	18.52632	4230.772	-	0.11	1.137856552	0.125164	Table SR3-1, H/W 1.375, W/W is .67, use 1 and
Top Inlet Turn	22	3000.215	-	0.11	0.572206835	0.062943	Table SR3-1, H/W app 1, also W/W, Co=1.15.
Screen 1	22	3000.215	-	0.32	0.572206835	0.183106	Table CR6-1, n=.8, A/A=1
Screen 2	22	3000.215	-	0.32	0.572206835	0.183106	
Contraction	22	3000.215	-	0.23	0.572206835	0.131608	Table ER4-1, A/A=2.24, theta=12, use 2 and 10

Total Loss		
	1.454687	inH2O
	7.564374	lbf/ft2

Inputs	Value	Units
Roughness	0.003	ft
Target	75	mph
	6600	fpm
Test Section width	1.5	ft
Test Section height	1	ft
CFM	9900	ft3/min
density air	0.0765	lbm/ft3
density water	62.4	llbm/ft3
Motor Efficiency	0.95	N/A
Hydraulic Efficiency	0.6	N/A

Outputs		
Reversible Power Requirement	lbf*ft/s	1950.19029
	hp	3.54580053
	W	2644.10345
Efficiencies	Hydraulic	0.6
	Electrical	0.95
Required Power	Hp	6.22070268
	W	4638.77799

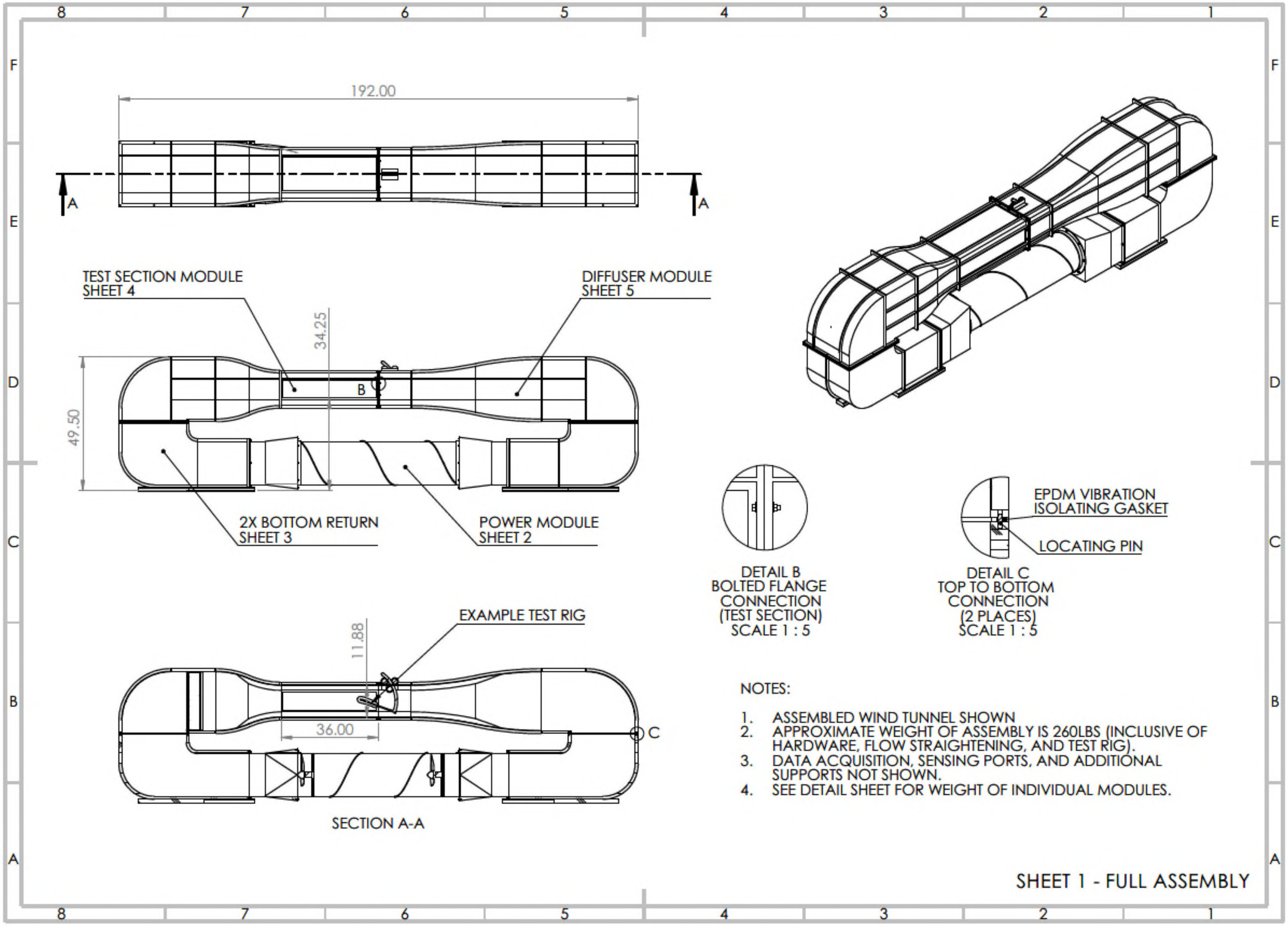
Loss Calculations							
Fitting	Dh	V	Length	Co	Pv	Loss	Notes
	(in)	(fpm)	(ft)	-	English	(inH2O)	
Test Section	14.4	8753.522	4	0.01	4.87095169	0.04871	
Diffuser	14.4	8753.522	-	0.14	4.87095169	0.681933	Table ER4-1 with 18x12 inlet and 22x22 outlet,
Diffuser Turn Top	22	3750.269	-	0.11	0.89407318	0.098348	Table ER3-1, use ratio of 1 for both sides - Co
Diffuser Bottom Turn	22	3750.269	-	0.11	0.89407318	0.098348	Table ER3-1. Width ratio is .67, so use .6 -
Bellmouth Inlet	18.52632	5288.466	-	0.03	1.777900862	0.053337	Table ER2-1, assume bell mouth faired. r/D is
Round Tube	16	7090.353	4	0.009	3.195831404	0.028762	
Bellmount Exit	16	7090.353	-	0.06	3.195831404	0.19175	Table SR4-3, use .5 area ratio and 45 degree
Bottom Inlet Turn	18.52632	5288.466	-	0.11	1.777900862	0.195569	Table SR3-1, H/W 1.375, W/W is .67, use 1 and
Top Inlet Turn	22	3750.269	-	0.11	0.89407318	0.098348	Table SR3-1, H/W app 1, also W/W, Co=1.15.
Screen 1	22	3750.269	-	0.32	0.89407318	0.286103	Table CR6-1, n=.8, A/A=1
Screen 2	22	3750.269	-	0.32	0.89407318	0.286103	
Contraction	22	3750.269	-	0.23	0.89407318	0.205637	Table ER4-1, A/A=2.24, theta=12, use 2 and 10

Total Loss	2.272949	inH2O
	11.81934	lbf/ft2

B. PRELIMINARY DRAWING

B.1. Overview

The following sheet shows the full assembly for a prototype wind tunnel. The drawing is based on a detailed model to determine assembly weight, interferences, bolting requirements, and ability to transport the design when disassembled.



NOTES:

1. ASSEMBLED WIND TUNNEL SHOWN
2. APPROXIMATE WEIGHT OF ASSEMBLY IS 260LBS (INCLUSIVE OF HARDWARE, FLOW STRAIGHTENING, AND TEST RIG).
3. DATA ACQUISITION, SENSING PORTS, AND ADDITIONAL SUPPORTS NOT SHOWN.
4. SEE DETAIL SHEET FOR WEIGHT OF INDIVIDUAL MODULES.

C. MOTOR FLYER

If You're Looking to Go Brushless, Go With E-flite®

From small inrunners for geared park flyers to big, powerful outrunners designed for up to 1.60-size planes—whatever type of electric powered flying fun you're into, E-flite's advanced line of powerful brushless motors has exactly what you need.

Hangar 9 P-47
Thunderbolt 150
(HAN2700)

Electric Power on a Large Scale: Power 46 to Power 160 Outrunner Motors

E-flite's big Power Series motors give .40- to 1.60-size pilots the clean, quiet convenience of electric power with a big emphasis on power. Pitted against any of their equivalent glow engine counterparts, these lightweight, high-torque, high-output motors will more than satisfy the most power-hungry pilot.

Hangar 9 Pulse XT 40
(HAN4100)

Suggested Applications:
Power 46—Hangar 9® Pulse XT 40; Hangar 9 Alpha 40; Hangar 9 Ultra Stick 40
Power 160—Hangar 9 P-47 Thunderbolt 150; Hangar 9 27% Extra 260

Superb Mid-Size Plane Power: Power 10 to Power 32 Outrunner Motors

Electric power is ideal for mid-size pilots who don't really care to mess with tuning a glow engine. This is where E-flite's smaller Power Series motors really shine. They're easy to use, don't require a lot of support equipment and are inexpensive to buy and operate. Like the bigger Power Series motors, they're clean and quiet, but provide excellent power and torque for their size.

E-flite J-3 Cub 25
(EFL4000)

Suggested Applications:
Power 10—E-flite Brio 10
Power 25—E-flite J-3 Cub 25, E-flite Ultra Stick 25e

Adding E-flite brushless outrunner power to any aircraft is easy because all E-flite motors include a motor mount, prop adapter and mounting hardware.

Power Outrunner Motors	Item #	Input Watts	Resistance	Idle Current	Continuous Current	Max Burst Current	Cells Ni-Cd /Ni-MH	Cells Li-Po	Weight	Overall Diameter	Shaft Diameter	Overall Length
Power 10 BL, 1100Kv	EFLM4010A	375W	.04 ohms	2.10A	30A	38A	6–10	2–3	4.3 oz (122 g)	1.4in (35mm)	.20 in (5mm)	1.60 in (42mm)
Power 15 BL, 950Kv	EFLM4015A	425W	.03 ohms	2.00A	34A	42A	8–12	3–4	5.4 oz (152 g)	1.4in (35mm)	.20 in (5mm)	1.90 in (50mm)
Power 25 BL, 870Kv	EFLM4025A	550W	.03 ohms	2.40A	32A	44A	10–14	3–4	6.7 oz (190 g)	1.4in (35mm)	.20 in (5mm)	2.10 in (54mm)
Power 32 BL, 770Kv	EFLM4032A	700W	.02 ohms	2.40A	42A	60A	10–14	3–4	7.0 oz (200 g)	1.7in (42mm)	.20 in (5mm)	1.90 in (50mm)
Power 46 BL, 670Kv	EFLM4046A	800W	.04 ohms	3.90A	40A	55A	12–16	4–5	10.0oz (290 g)	2.0in (50mm)	.24 in (6mm)	2.15 in (55mm)
Power 60 BL, 400Kv	EFLM4060A	1200W	.06 ohms	2.70A	40A	60A	16–24	5–7	13.0oz (380 g)	2.0 in (50mm)	.24 in 6mm)	2.40 in (62mm)
Power 110 BL, 295Kv	EFLM4110A	1900W	.03 ohms	1.30A	55A	65A	24–32	8–9	17.5oz (490 g)	2.5in (63mm)	.30 in (8mm)	2.10 in (54mm)
Power 160 BL, 260Kv	EFLM4160A	2500W	.02 ohms	1.60A	60A	75A	28–32	9–10	23.0oz (650 g)	2.5in (63mm)	.30 in (8mm)	2.50 in (64mm)

HORIZON HOBBY

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