SAE Aero Design

Design Report Guidelines

Introduction

Technical report writing is a skill that is different from informal writing – letters, notes, email – and, like all skills, needs practice to be mastered. The SAE Aero Design Competition provides an excellent opportunity for students to exercise this skill. This document provides guidelines to help design teams write clear, succinct, and data-rich reports. The guidelines are grouped in four areas: organization, writing process, writing clearly and succinctly, and content.

Order of Precedence

This document is a reference only. In the event of a conflict between this document and the published SAE Aero Design Rules, the rules shall govern.

Organization

Reports are written for a person or group to read, and **these readers have a purpose for reading the report**. In the SAE competition, the readers are judges, and their purpose in reading is to grade the paper. Therefore, the design team authors should write the design report using techniques that make it easy for the judges to grade**.** Organizing the report for the reader's purpose is the first technique in effective technical writing: **know your audience**.

Outline

The judges grade to criteria found in the rules and the scoring rubric. The rules predominately cover administrative aspects of the report – page limits, formats, and specific graphs and drawings. However, addressing the following topics will provide technical depth to the paper content:

Explain the team's thought processes and engineering philosophy that drove them to their conclusions

Detail the methods, references and standards, procedures, and where applicable, the calculations used to arrive at the presented solution should be contained in an appendix.

- These topics should be included within technical paper:
  - Vehicle configuration selection
  - Wing plan form design including airfoil selection
  - Drag analysis including three-dimensional drag effects
  - Aircraft stability and control
  - Power plant performance including both static and dynamic thrust, performance prediction
  - Structural Loads and Critical Margins
  - Testing as appropriate
  - Other as appropriate

The scoring sheet topics are not parallel to these instructions, so how should the design team organize the report to make it easy for the judge to grade? The secret to successful writing is simple: **organize the report around the scoring rubric,** and building an outline that parallels the applicable grading criteria, see Appendix A for a sample outline. Address the above topics as subsections in the appropriate section of the outline. Although it may be harder to write the report to an outline, **it will be easier for the judges to grade.** Covering the topics listed herein forces the team to address topics the judges must grade, and develop necessary data, which should benefit the overall design.

Writing Process

Writing a multi-page report can be made less daunting by using a multi-step process. The first step is described above, generating an outline that addresses the reader's purpose. The next steps, described below, help in generating a data-rich, well-edited report.

Allocate Pages

Allocate the technical paper's pages in accordance with the SAE Aero Design Competition Rules pages to the sections of a team outline. The allocations should reflect the emphasis areas of the team's design. **Do this before writing** begins, and adjust after reviewing the first draft. For each page of the report, define the topic to be discussed **and** the message to be delivered. Make writing assignments for each page. **Giving authors page-by-page assignments makes it easier to attack the writing –** they are writing only one page at a time.

Create the Figures

Most judges will be engineers, and engineers are graphically inclined - they can understand a concept more quickly when looking at a picture. Use figures as an opportunity to communicate trends and design points. Figures can send a powerful message and are an excellent way to communicate. Use Paretos to communicate design, weight and CG sensitivities. Build each page around at least one figure. **Create the figures first, and review them before starting to write.** Each figure needs a message which should be summarized in the figure title. **Make the figures data-rich, but legible** (9-point font is a minimum size - another advantage of using figures is that the rules do not constrain type font or spacing on figures). **Equations should be kept to a minimum**, but can be incorporated in figures to save space. Use figures/graphs to communicate design trends, optimization corners and design points: a creative way of expressing these data sets can save paper space for content. The figures can also be the basis for the oral report. Trends and design points are best communicated in graphical illustrations.

Include a top level, labeled system picture on sheet one of the written volume in the technical paper's executive summary. An early big picture discussion will assist in launching into the details that you wish to cover in the technical paper.

Draft the Text

Use text to highlight, explain, or further develop the major points of the figure. Writing guidelines for clarity and succinctness are presented in a subsequent section.

Edit the Text & Figures

Take the time to edit the document at least twice. A good approach is to perform one edit cycle based on a group review of the draft document (called a Red Team). Have the Red Team members read the document as judges, supplying them with a scoring sheet and a copy of the rules.

Create the Final Document

Although several persons may contribute to the writing process, one team member should make the final version. This person works to achieve a consistent style to the text and to make the messages consistent.

Schedule the Effort

Although this is the first step, I describe it last so that the reader can see what the team needs to schedule! A good report takes more than a week to create. **One month is a guideline for the duration of the writing effort.** Create a schedule of the above tasks and status it regularly. **An efficient method is to establish the outline, page allocations, and figures early in the project, so the team can generate the necessary data as the design progresses.** This reduces both the last-minute cram and the amount of unused documentation.

Writing Clearly and Succinctly

The best outline, figures and data can be undone by poor writing. Publications are available that discuss this topic in depth (I recommend books and articles by Paula LaRocque). Listed below are seven basic techniques for creating effective technical prose.

Active vs. Passive Voice

Sentences written in **active voice** consist of a subject acting (via a verb) upon the object. Sentences written in passive voice consist of a subject being acted upon by a usually unidentified noun. Simple examples:

The team calculated the drag of the aircraft. (Active)

The drag of the aircraft was calculated by the team. (Passive)

In the second example, the prepositional phrase *by the team* is usually not included, and must be inferred by the reader. In technical writing the subject of many sentences is often the same – the author or a design team – and passive voice relieves the author from continually repeating the subject. This may appear elegant, but **passive voice** produces longer, sometimes stilted sentences and **leads to dull reading**. Using active voice makes the writing lively – the reader sees an action being performed and knows who is doing it. An example from one of the design reports illustrates this point – the highlighted verbs are passive voice:

*Part of the initial design steps, after choosing the airfoil and getting its resulting Cl, included choosing a range of desired aircraft weights. Using these estimated ranges, a range of wing areas **was determined** that could satisfy the requirements. The operating ranges **were then narrowed** down and iterated until workable values **were obtained**. Once the required wing area **was known**, along with the taper ratio, the chord dimensions **were chosen**.*

Edited using active voice verbs (highlighted)

*After selecting the airfoil, the **design team established** a desired weight range for the aircraft. Using these weights and the Cl value of our airfoil, **we calculated** wing areas that provided the lift needed to achieve the takeoff requirement. **We iterated** this analysis and selected a wing area. The **team then selected** a taper ratio and established the chord dimensions.*

The example shows how the writer can alternate the first person (we) and third person (the design team) to alleviate monotony. Passive voice can be used occasionally to alter the sentence flow. A suggested ratio is one passive voice sentence for every two active voice sentences.

Eliminate Unnecessary Words

Casual conversation uses many introductory phrases and colloquialisms. Using these extra words in a technical document, however, dilutes the meaning of a sentence. In a page limited document, these words also reduce the space available for additional or larger figures, or another sentence. Examples of unnecessary words:

- now that
- from the start
- to go about this
- simply
- the next step
- from this

A before/after example illustrates how many words can be eliminated without removing content – unnecessary words are highlighted:

Now that *the type of wing* ***that was going to be built*** *was selected,* ***the next step*** *was to select the airfoil* ***that would be used****.* ***To go about this****, research was conducted on* ***different types*** *of airfoils through* ***various*** *airfoil databases.* ***During the search*** *a program called Profili was discovered.*

After – edited to contain only necessary words:

With the wing configuration selected, we then evaluated airfoil options. We researched airfoil databases and found a program called Profili.

Avoid words like "*utilized*" or ", *which*". Instead use shorter words like "*use*" and "*that*". These are shorter phrases that can save your page count, delivering the same message.

Avoid making up long introductions to major sections. A single sentence describing the topics to be covered in the subsections is adequate. An example is shown below:

2.0 Design Process

The following section describes the research we performed, our design and analysis process, and our design selection process.

Eliminate phrase duplication. In the before/after example below, the original sentence has two sets of duplications, one underlined and the other in boldface:

Additionally, fuel burn ***has little effect on*** *the center of gravity as well* ***(less than a quarter of an inch shift).***

After - with duplications removed:

Fuel burn shifted the center of gravity less than 0.25-in.

Use *due to* Correctly

Since technical reports often describe cause-effect relationships the phrase *due to* is often (over)used. The following guideline will mitigate overuse:

Due to is a substitute for *caused by*. It is **not** a substitute for *because of*.

Test all uses of *due to* with the guideline. Replace with *because of* where appropriate, and also mix in *caused by* to add variety.

Talk Technical

Do not use adjectives to quantify a topic, **use data**. Here are examples of **expressions that should not be used in a technical report**:

- large amount/quantity/effect
- several
- significant increase/decrease
- some
- extensive range
- a few
- low/high level of
- many
- excellent agreement/levels

State a value or range of values, an order of magnitude, or a percentage. This provides the reader with a clear understanding of the magnitude of the data comparison.

Each paragraph and figure should deliver a powerful technical message, ask yourself, "*what does this paragraph convey to the reader about my design decisions?*" Avoid equations in the text, if you feel it's necessary to include an equation, **put it in blank space in a figure.**

Many technical ideas are communicated more effectively with the use of plots to communicate trends, design points, sensitivities and cost-benefit of trades. Industry flirtation with 6σ has generated many useful communication tools which can help develop quantitative data for seemingly qualitative topics. Examples are Paretos, PICK charts, etc.

Use your page count effectively; **communicate your design as a whole**, not individual pieces. Don't miss the forest for the trees, make sure you communicate the design as a whole before delving into the details.

Explain Symbols

Introduce symbols and acronyms in the text to spare the reader from constantly referring to the List of Symbols and Acronyms. The first time a symbol is used, provide the definition (in parentheses is adequate). For an acronym, spell out the words of the acronym then follow with the acronym in parentheses.

Cite References

A list of references at the end of the report does not help the reader understand how the references were used in the design process. Where appropriate in the report, cite the reference. If the references are numbered in the list of references, the citing can be worded in parentheses - (*see Reference X*).

Plagiarism, the practice of copying someone else's' work without citation, is **not permitted** in technical paper writing. Technical writing may quote from cited source material, but should be the author/team's own original work.

Know Your Audience

Most judges will be engineers: primarily mechanical and aeronautical; though some judges are from management, hobbyists, and other engineering disciplines. Industry requires concise writing, keep equations **and textbook discussions** to a minimum. Your judges went to many of the same engineering education institutions, had many of the same textbooks and professors, they don't need an education in the topic, they want to know the performance of your design. Succinctly: **Know Your Audience**.

Long technical papers should **always** include a summary of results in the first page of text (do not exceed), an **Executive Summary**. This page should communicate top level layout, innovative features, expected results and may include small charts of critical details. This summarizes for the audience the key messages you will convey in the detailed discussion.

A good rule of thumb for paper and presentation organization is: "tell them what you're going to tell them; tell them; tell them what you told them."

Keep Verb Tenses Simple

A technical report usually combines a history of work performed with a description of the result. Confusing tense structure can be avoided by using the following guidelines:

- When describing the design development process, write in the past tense. The work was done in the past. The obvious exception is description of follow-on work or work being performed as the report is written. For these cases, use the future or present tense respectively.
- When describing the features of the design, or results of the design process, use present tense (e.g. *the data show*, not *the data showed*). The features, once established, are independent of time. An exception is when describing a feature that was subsequently changed, past tense is appropriate.

Limit using past perfect, present perfect, and conditional tenses, as they add words. Examples:

Instead of –	*Use –*
has been, have been	was
would be	is

Before/after examples of effective use of tense follows with the verbs highlighted:

Example 1 – present, past, present perfect, and future tenses used:

The fuselage ***is*** *a simple cylindrical structure constructed from the EPP foam. It* ***is*** *permanently attached to the tail boom and will house the payload. This cylindrical structure* ***was chosen*** *for its aerodynamics and ease of construction. It* ***has been*** *positioned below the wing and centered on the center of gravity so that the addition of the payload weights* ***doesn't*** *disturb the center of gravity (CG) positioning. The payload itself* ***will*** *consist of lead bars cut to the length of the fuselage.*

After – present and past tenses used:

A cylindrical fuselage constructed from EPP foam ***is*** *permanently attached to the tail boom. The cylindrical structure* ***was*** *selected for its desirable aerodynamics and ease of construction. The fuselage, which carries the payload,* ***is*** *positioned below the wing on the projected center of gravity (CG) to minimize CG shift with payload addition. The payload* ***consists*** *of lead bars cut to the length of the fuselage.*

Example 2 – past and conditional tenses used:

*A choice **needed to be** made whether to put the hatch on the top or bottom of the wing, each **had** its pros and cons. Putting the hatch on the bottom of the wing **had** the benefit that if the hatch **was** not installed perfectly it **would have** less effect on the lift the wing created, but **would mean** the plane **would have** to be turned up side down to load and additional support **would be** required to keep the weight from falling out. A hatch on the top of the wing **would be** easy to load and the supports already built into the wing **could be** used to carry the weight, but if the hatch was not perfect it **would greatly reduce** the lift of the wing.*

After – present and past tenses used:

*We **traded** two options for the location of the payload hatch: (1) on the top of the wing, and (2) on the bottom of the wing. The figures of merit **evaluated** were lift impact, weight, and ease of loading. The bottom location **is** less sensitive than the top location to lift loss caused by hatch misalignment. The top location **is** lighter because the hatch does not need to support payload weight. The bottom location **requires** turning the aircraft over to load payload.*

Establishing Content

The following are observations regarding technical weaknesses identified in many of the submitted technical papers over the past few years. Some of the thoughts in this section will help with creating a data-rich technical paper as well as suggest some avenues of research and communication of each team's design in a familiar format for most judges.

Design Process Notes

Establish Requirements

Communicate to the audience your design requirements, do not parrot the SAE requirements, but the requirements you derive from the rules: loads, accelerations, shocks, endurance, power plant, electrical – demonstrate you understand the detailed problems to solve. I.E. deriving minimum loads, endurance, etc. are good places to start.

Document Trade Studies

Document trades with *quantitative* evidence – it's not a sound engineering decision if it is not supported by data. Qualitative and subjective evidence are not demonstrations of sound engineering positions.

- **Evaluate trades based on performance relative to requirements.** Evaluate trades to a baseline (previous entrant, target score, performance metric).
- **Using last year's plane as a baseline may not be a competitive starting position.** Be careful using last year's model as a baseline. Especially if the baseline aircraft wasn't in the upper bracket – (hint: this is a good topic: discussion of departure from a design due to a fatal flaw, or maintaining a design with modifications based on failure analysis and corrective action).
- **Designing to a target score can be dangerous** as another team's design may exceed the selected target score.
- **Comparing trades to a performance metric is best**, as this lets each design speak for itself and the best performing option stands out quantitatively relative to the others.
- Use PICK charts (Possible, Implement, Challenge, Kill) to communicate the number of trades as well as cost-benefit. **Cost-benefit can offer powerful rationales for pursuit**

of a concept as well as abandonment of a concept. However, every trade needs its day in court – let the performance numbers speak.

- **Use Pareto's charts to your advantage** (a graphical representation of a sensitivity analysis): Pareto analysis is a powerful organization and communication tool – this tool can be used to focus attention to what's important quickly. 90% drivers in a Pareto are design variables which should have strong documented design trade support.

Innovation

List things that are truly innovative: i.e. concepts hobbyists regularly employ are not new innovations.

Suggested Reference Materials

The following references are an excellent place to start designing a competitive aircraft for both the aerodynamic and mechanical disciplines. Take care not to neglect either of the two primary disciplines of this competition. These references are the minimum resources for design, layout and analysis and cover most topics in sufficient detail to build a competitive aircraft for this competition.

- Mechanics of Flight: Second Edition; Warren Phillips
- Aircraft Design: A Conceptual Approach; Raymer
- Mechanical Engineering Design: Shigley's: Eighth Edition; Budynas and Nisbett
- Roark's Formulas for Stress and Strain; Warren Young, Budynas, & Sadegh
- Model Aircraft Aerodynamics; Simons
- Dr. Nicolai's Whitepaper
- Introduction to Flight; Anderson
- Flight Stability & Automatic Control; Nelson
- MIL-STD-8785
- FAA-H-8083-1A

Analytical Notes

Loads Derivation

Derive and communicate design loads before designing/selecting anything, it's often the case that the highest CL airfoil, while attractive on the surface, can be realized as a penalty; too much CL can cause too much induced drag on the takeoff roll out. Therefore, the highest CL airfoil may not be the best for the competition, evaluate what airfoil you need based on performance required to be competitive in the competition. Evaluate flight pattern to derive load requirements: consider that designs can be lift limited in turning flight instead of takeoff.

Analytically **apply loads logically to parts:** e.g. a wing is likely most heavily loaded during a turn, not during landing shock or takeoff; landing gear is most heavily loaded with the application of a landing shock as are weight bearing elements of the fuselage. – Prove derivation and application of loads. **A surefire way to over/under design is a one load fits all sort of approach.**

Finite Element Modeling

Keep Finite Element Model (FEM) figures to a minimum, **don't waste time creating and evaluating FEM where a conservative hand-calculation will do** (use Roarke's for hand calculations). The inclusion of finite element model is attractive, but most airplane structures are simple enough (beams and plates) for hand calculation to demonstrate adequate performance margin. **Margins are a very effective method to communicate structural design adequacy**, and only close margins need to be discussed in the paper and considered for FEM (Margins less than .15).

Communicating Analysis

Communicate applied factors of safety to be used in analysis. Factor of Safety is ***not*** the same as margin. **Factors of Safety help cover certain analysis inefficiencies/assumptions**, a fudge factor for dynamics and unanticipated load combinations. **Margin is a measure of how much over load** could be tolerated by a design and should be calculated as: Margin of Safety = allowable stress / (Factor of Safety * actual stress) – 1. **Communicate design structural "goodness" with a critical margins table early in the mechanical section of the paper.** After communicating design loads, communicate applied factor of safety and performance margins in a simple table.

Hint: Large structural margins may also indicate the opportunity for structural weight reduction. Recommend someone on the team be responsible for tracking weight and CG placement in all configurations very early on in the design process, this individual should assist with the initial layout.

Appendix A – Sample Outline

Cover Page (1 page)
Statement of Compliance (1 page)
List of Figures and Tables (1 page)
1.0 Executive Summary (1 page MAX)
- 1.1. System Overview
- 1.2. Competition Projections/Conclusions
- 1.3. Discriminators

2.0 Schedule Summary (0.5 pages)
3.0 Table of Referenced Documents, References, and Specifications (0.5 pages)
4.0 Design Layout & Trades (5 pages)
- 4.1. Overall Design Layout and Size
- 4.2. Optimization (Design Sensitivities, System of Systems: Planform, layout, powerplant, etc.)
  - 4.2.1. Competitive Scoring and Strategy Analysis
  - 4.2.2. Optimization and Sensitivity Analysis
- 4.3. Design Features and Details (Subassembly Sizing)
- 4.4. Interfaces and Attachments

5.0 Loads and Environments, Assumptions (2 pages)
- 5.1. Design Loads Derivations (e.g. accelerations, landing shock, etc.)
- 5.2. Environmental Considerations

6.0 Analysis
- 6.1. Analysis Techniques (1 page)
  - 6.1.1. Analytical Tools (CAD, FEM, CFD, etc.)
  - 6.1.2. Developed Models (Take-Off, Turning Flight, etc.)
- 6.2. Performance Analysis (3 pages)
  - 6.2.1. Runway/Launch/Landing Performance
  - 6.2.2. Flight and Maneuver Performance (Incl. Surface Sizing)
  - 6.2.3. Shading/Downwash
  - 6.2.4. Dynamic & Static Stability
  - 6.2.5. Aeroelasticity
  - 6.2.6. Lifting Performance, Payload Prediction, and Margin
- 6.3. Structural Analysis (3 pages)
  - Critical Margins Table
  - 6.3.1. Applied Loads and Critical Margins Discussion
  - 6.3.2. Mass Properties & Balance

7.0 Assembly and Subassembly, Test and Integration (2 pages)
8.0 Manufacturing (2 pages)
9.0 Conclusion (1 page)
- List of Symbols and Acronyms (0.5 pages MAX)
- Appendix A – Supporting Documentation and Backup Calculation (2 pages)
- Appendix B – Technical Data Sheet for your class (1 page)
- Drawing 11X17 (1 page)

This sample outline results in a technical paper 29 pages in length, satisfying the 30 page requirement with one page of margin.