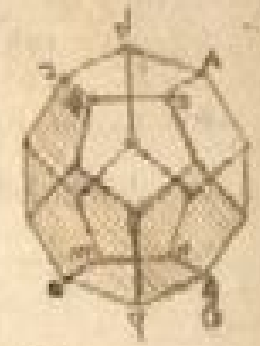
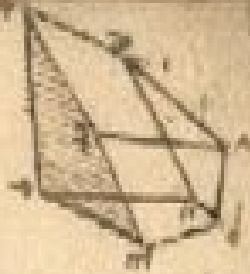


Communication in Science / I

March 2015

Samo Stanič

Univerza v Novi Gorici



Course structure

- Introduction
- Structure and process
- Language
- Illustrations
- How to publish in top journals, i.e. *Elsevier*
- **Practical work**

Why learn scientific writing?

- You will have to **write a thesis**
- You may have to write a **scientific article**
- You **will be judged by what you write** and what you present:
 - Content
 - Structure
 - Style

What Should You Learn?

Scientific writing is an essential skill for **anyone** wishing to pursue a career in **any scientific field**.

This course will prepare you to participate in professional scientific communication using **accepted format and style**.

Scientific writing is the process of researching or experimenting with a problem and then presenting findings in the context of current work. This type of writing has to be **easy to skim for important findings or conclusions**.

It is utilized in **peer-review journals, grant proposals, theses and dissertations**, lab reports and literature reviews.

Necessary Skills

- how to describe an **outline**, determine its value and then develop his/her own outline before writing a paper
- how to **format papers**, including the abstract, materials and methods, results, conclusions and works cited
- how to research literature using both **online** and traditional **hard copy** methods; how to evaluate literature for relevant content and incorporate it into the writing
- proper use of grammar, verb tense, active and passive voices and sentence structure; proper division of sentences and paragraphs, elimination of excess language and use of **concise, common, exact wording**

Writing is learned by writing

- **Practice, practice, practice**
- Choose good role models
- Study good examples
- Learn the rules and the techniques



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Introduction

- Importance of precision
- Principles
- Structure
- Format
- *Introduction to LaTeX*



Survey (Richard M. Davis)
Successful engineers spent 25%
of work week writing



Survey (Wisconsin)
Professional engineers found
writing their most useful subject in
college



Survey (Virginia Tech)
Recruiters claim that engineers need
more work on their writing



Explosion was caused by failure of O-rings in the solid rocket boosters

Engineers knew of O-ring problems well before fatal launch

Engineers failed to communicate seriousness of problem

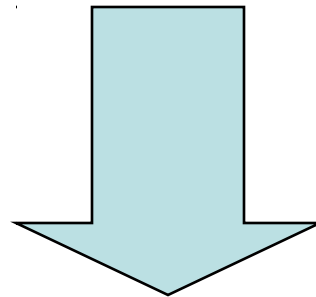
**Space Shuttle Challenger
(January 28, 1986)**

Scientists and engineers are called upon to communicate in many different situations

**Reports
Articles
Proposals
Web Pages**



**Conferences
Lectures
Meetings
Posters**

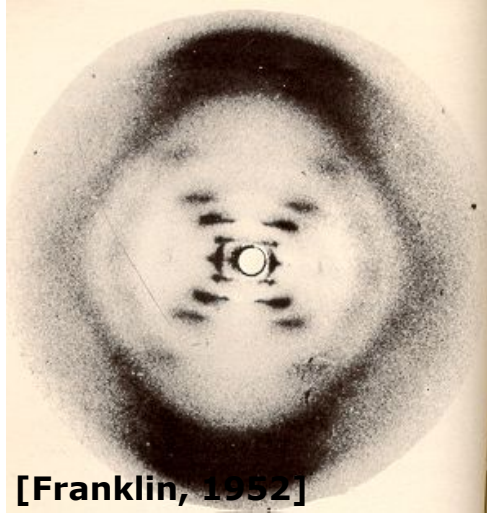


**specific
technical
audiences**

**general
technical
audiences**

**non-technical
audiences**

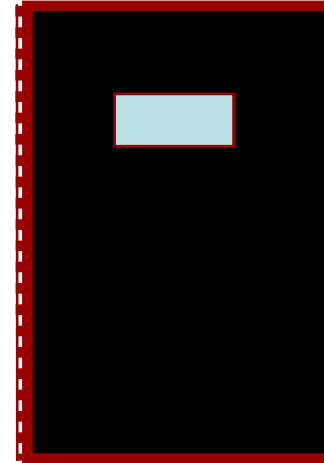
Subject Topic



Writing Constraints

audience

purpose



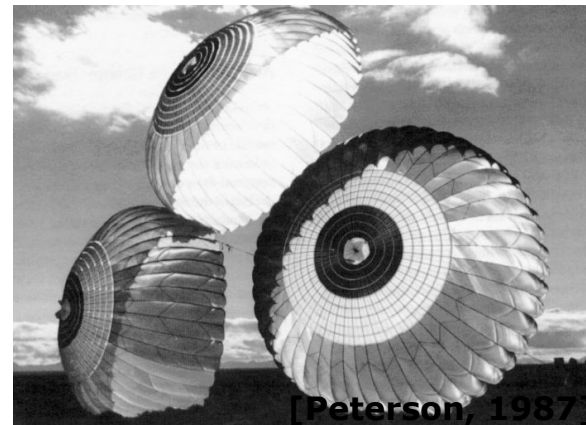
occasion

Purpose of Writing

To inform

To persuade

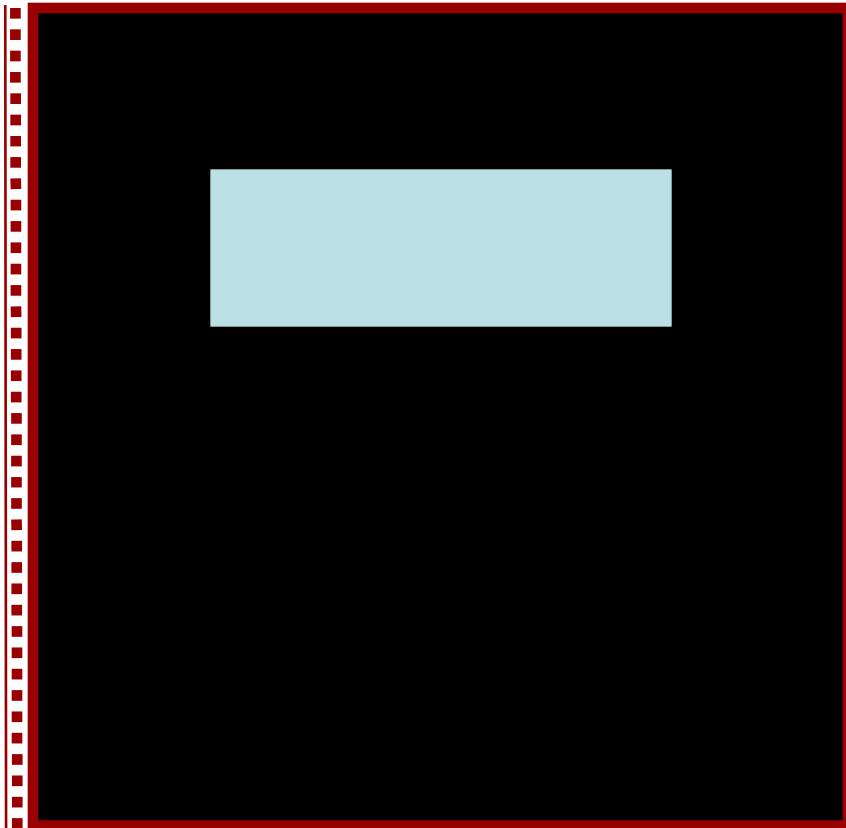
Writing Style



[Peterson, 1987]

You should begin the writing process by analyzing your constraints

Audience



Who they are

What they know

Why they will read

How they will read

Occasion

Format

Formality

Politics and ethics

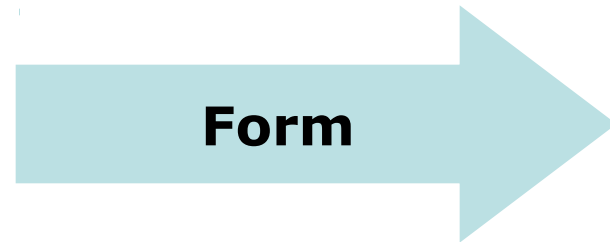
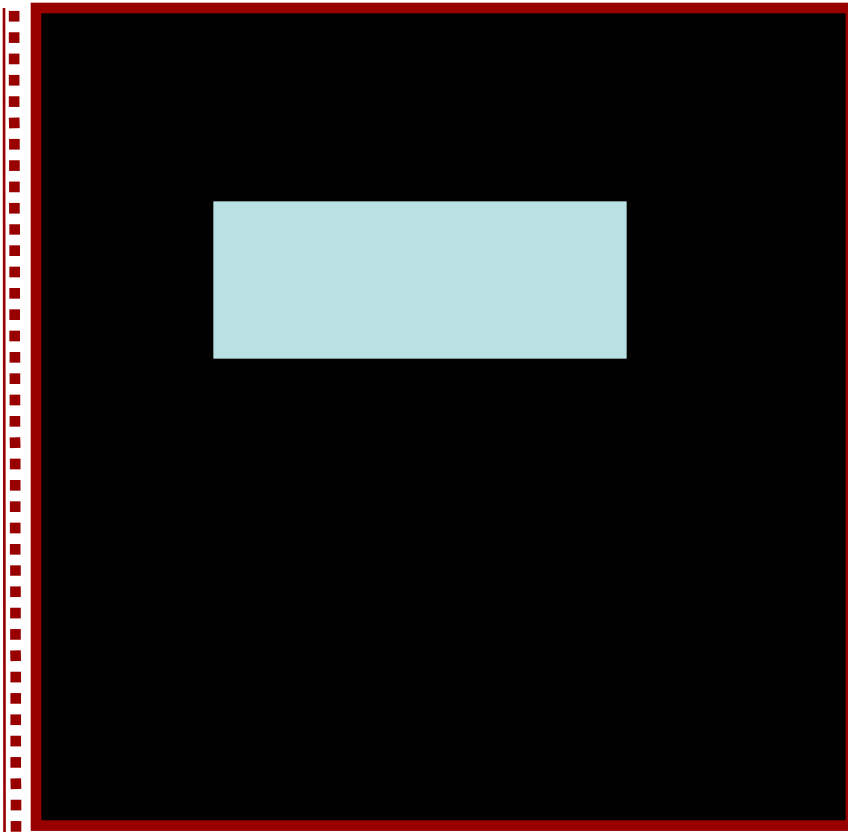
Process and deadline

Purpose

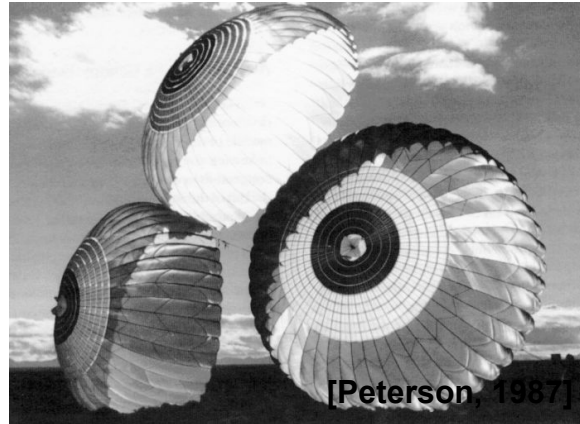
To inform

To persuade

Three aspects of writing affect the way that readers assess your documents



Style is the way you communicate the content to the audience

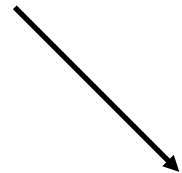
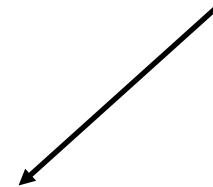
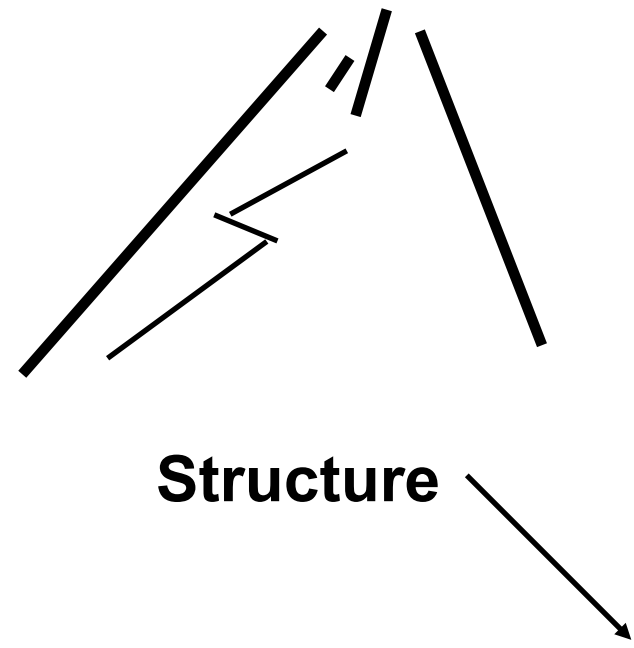
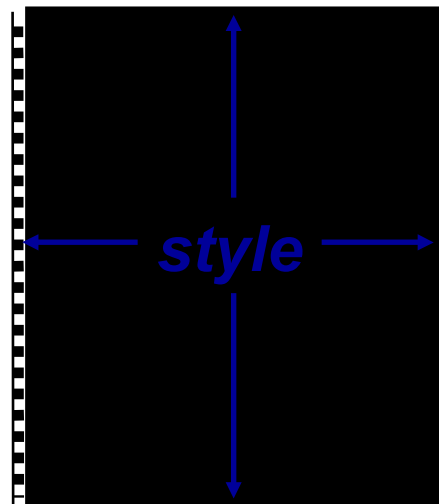


Illustration

words
wordswords
wordswordswords
wordswordswordswords
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wordswordswords

Language

Structure

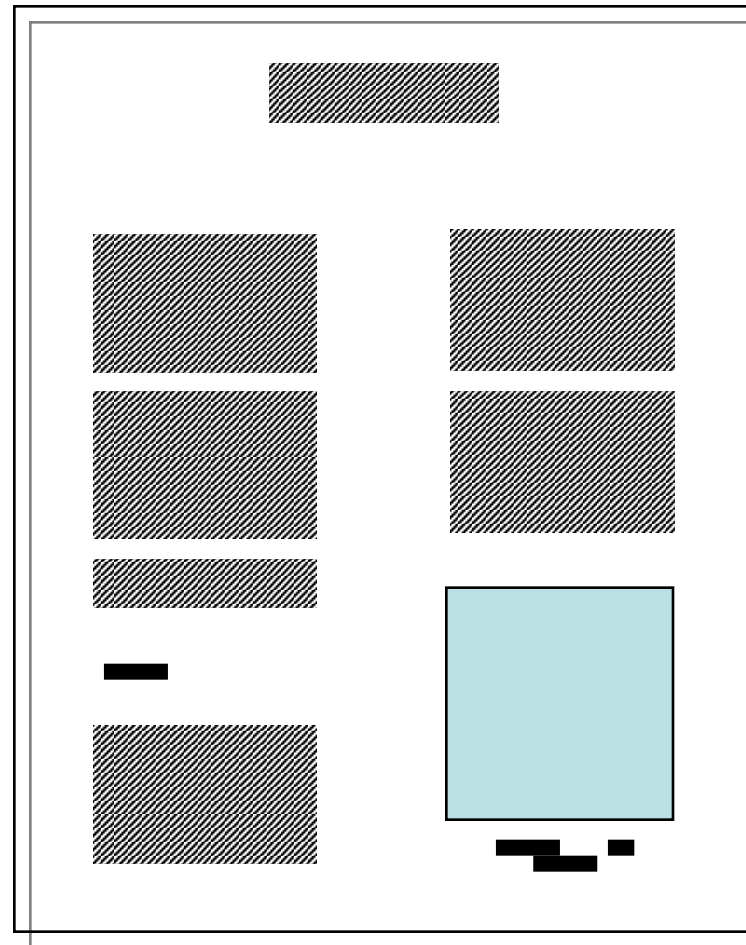


Form embodies the format and mechanics of the writing

format

typography

layout



mechanics

grammar

usage

punctuation

spelling

We can split the writing process into stages

“Getting in the mood”



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WRITING YOUR THESIS OUTLINE

NOTHING SAYS “I’M ALMOST DONE” TO YOUR ADVISOR/ SPOUSE/PARENTS LIKE PRETENDING YOU HAVE A PLAN

Wr

STEP 1 Aim for a respectable number of chapters:

THESIS OUTLINE

- 1.
- 2.
- 3.
- 4.
5. ← chapter #'s
- 6.
- 7.

5 = “That’s IT??”
6-7 = “Not bad”
8+ = “Are you crazy??”

STEP 2 Fill in the “freebies”:

THESIS OUTLINE

1. INTRODUCTION
2. LIT REVIEW
3. METHODOLOGY
- 4.
- 5.
- 6.
7. CONCLUSIONS

You’re half way done!

STEP 3 Make up titles for the “meat” chapters:

6. LIT REVIEW
3. METHODOLOGY
4. (THAT STUFF YOU DID YOUR FIRST YEAR)
5. (STUFF YOU’RE SUPPOSED TO BE DOING NOW)
6. (MAKE STUFF UP)
7. CONCLUSIONS

(It’ll be years before you actually have to work on that later chapter, and by then your thesis topic will have changed anyway)

STEP 4 Voilà! You just bought yourself another two years

So, how’s your thesis going? i have an outline!

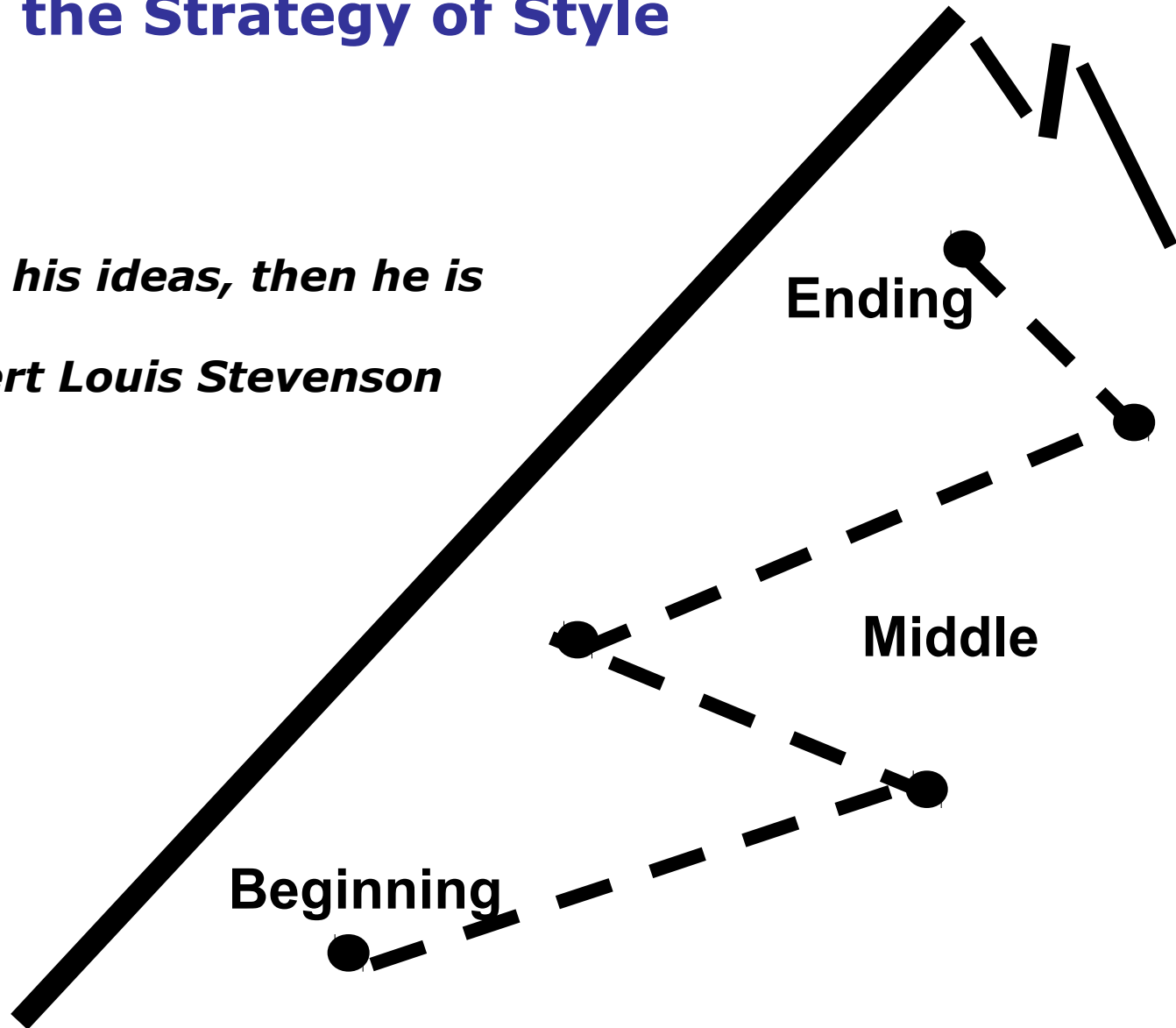
JORGE CHAM © 2006

www.phdcomics.com

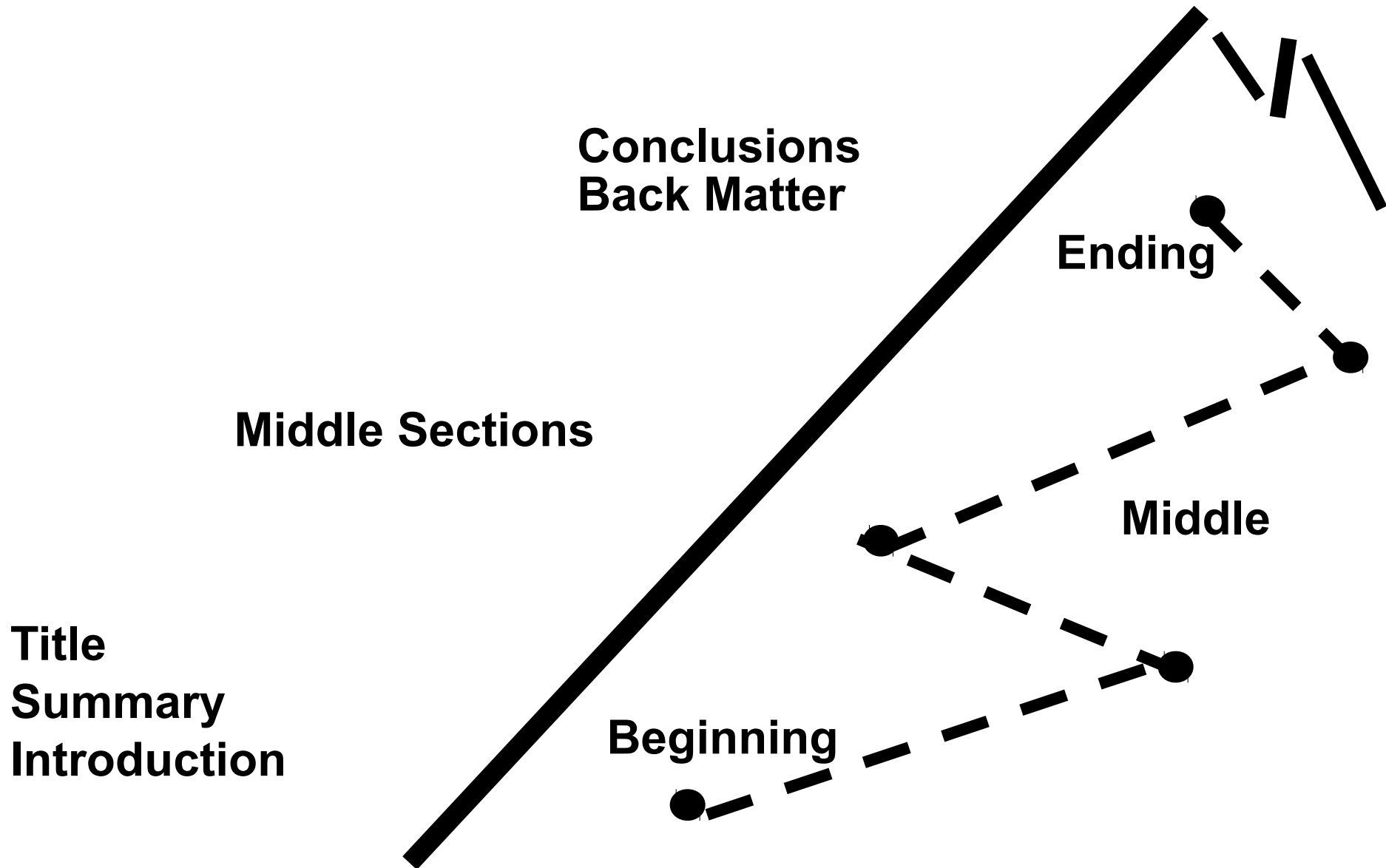
Structure: the Strategy of Style

*If a man can group his ideas, then he is
a writer.*

Robert Louis Stevenson



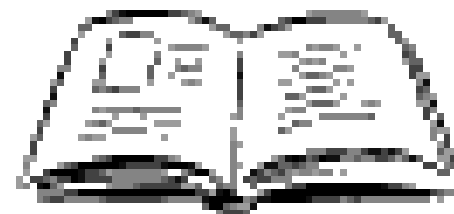
The organization of a scientific document can be viewed as a beginning, middle, and ending



Title **orients readers to document**



Summary **tells readers what happens in document**



Introduction **prepares readers for the middle**



A strong title orients readers to your area of work

**Effects of Humidity
on the Growth
of Avalanches**



**Effects of Humidity
on the Growth
of Electron Avalanches
in Electrical Gas Discharges**

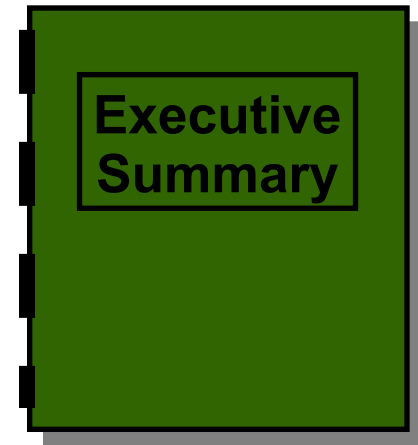
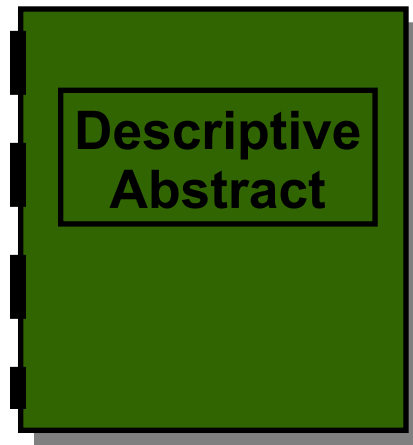
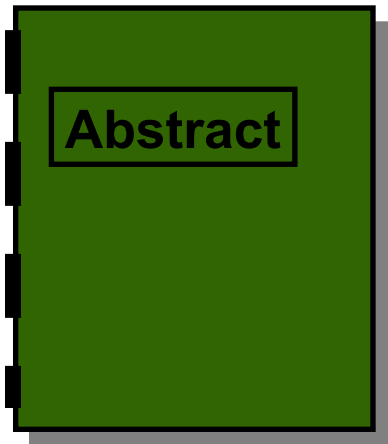
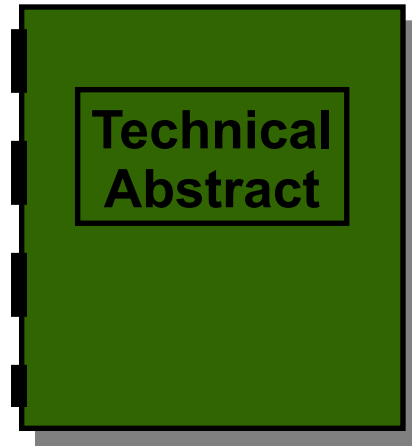
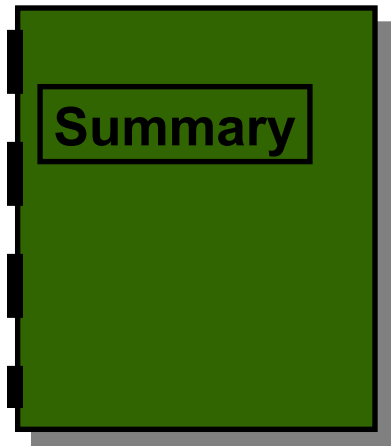
A strong title also separates your work from everyone else's work

**Studies on the
Electrodeposition
of Lead on Copper**



**Effects of Rhodamine-B
on the Electrodeposition
of Lead on Copper**

Several names for summaries exist



Although several names exist for summaries, there are essentially two approaches

This paper describes a new inertial navigation system for mapping oil and gas wells. In this paper, we will compare the mapping accuracy and speed for this new system against the accuracy and speed for conventional systems.

Descriptive

This paper describes a new inertial navigation system that will increase the mapping accuracy of oil wells by a factor of ten. The new system uses three-axis navigation that protects sensors from high-spin rates. The system also processes its information by Kalman filtering (a statistical sampling technique) in an on-site computer. Test results show the three-dimensional location accuracy is within 0.1 meters for every 100 meters of well depth, an accuracy ten times greater than conventional systems.

Informative

A document's introduction prepares readers for the discussion

Introduction

Topic?
Importance?
Background?
Arrangement?



The introduction defines the **scope** and **limitations** of the work

Women may not experience the same effects

Medical histories not considered

scope

**Proposed Study
on Effects of Alcohol
on Life Expectancy**

Ten-year study

**Three classes of drinkers:
non-drinkers
moderate drinkers
heavy drinkers**

Men surveyed

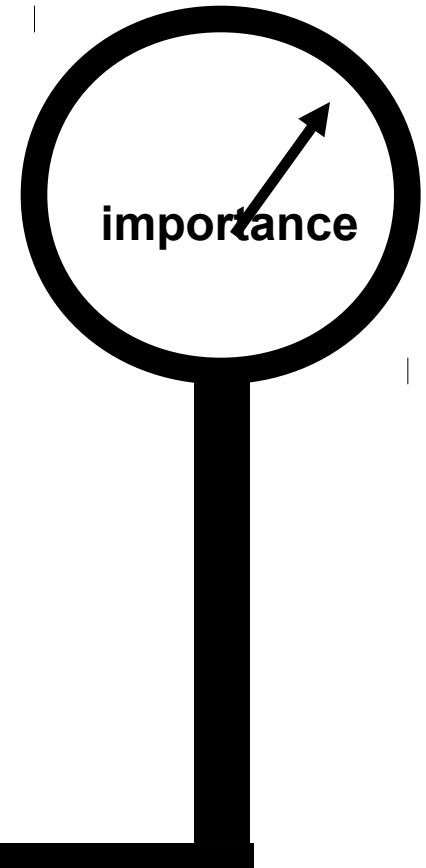
Other effects, such as exercise, not considered

limitations

A strong introduction tells readers why the research is important

This paper presents a design for a platinum catalytic igniter in hydrogen-air mixtures. This igniter has application in nuclear reactors. One danger at a nuclear reactor is a loss-of-coolant accident. Such an accident can produce large quantities of hydrogen gas when hot water and steam react with zirconium fuel rods. In a serious accident, the evolution of hydrogen may be so rapid that it produces an explosive hydrogen-air mixture in the reactor containment building. This mixture could breach the containment walls and allow radiation to escape.

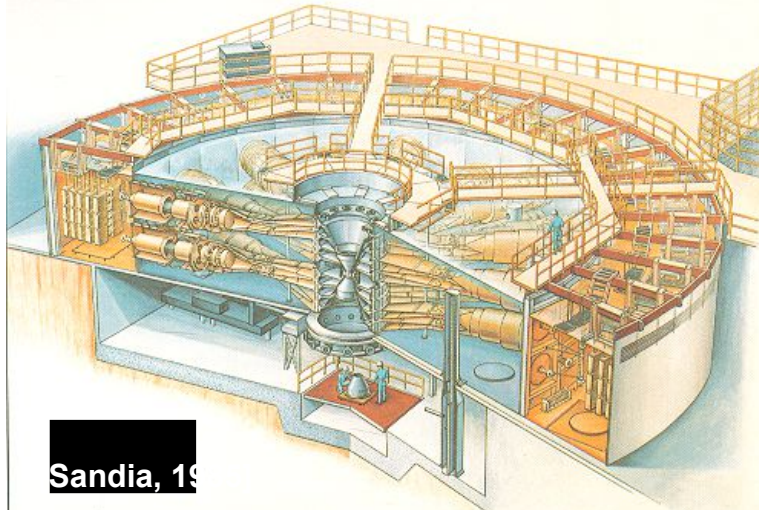
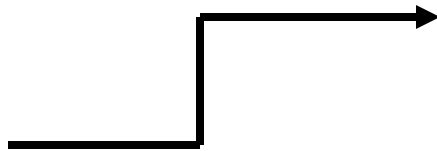
Our method to eliminate this danger is to intentionally ignite the hydrogen-air mixture at concentrations below those for which any serious damage might result.



In the middle of a report, you present your work

Choose a logical strategy

Make sections and subsections

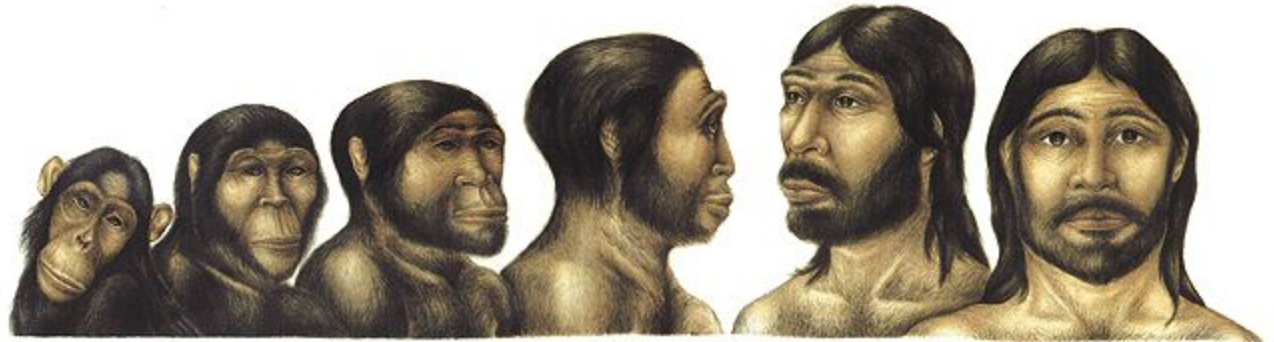


Sandia, 19

Heading
 Subheading
 Subheading
Heading
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 Subheading
 Subheading
Heading

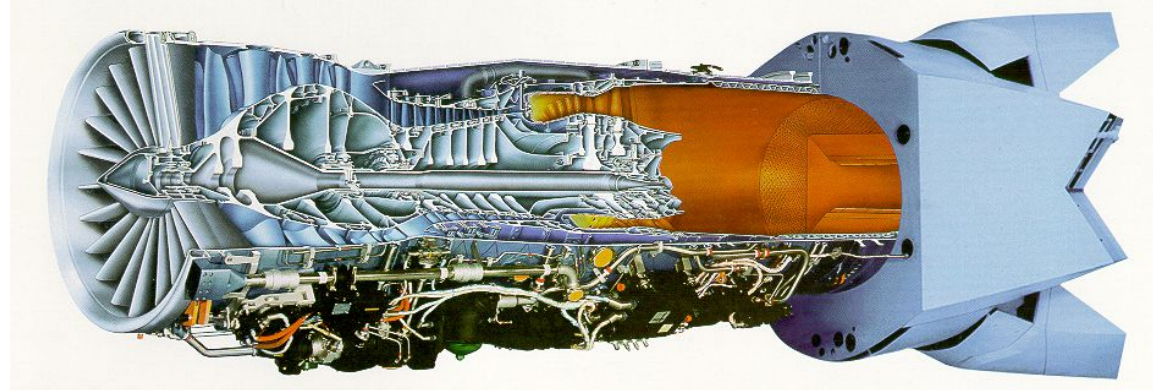
Common strategies exist for the middles of scientific reports

Chronological



[Maizels, 2001]

Spatial



[Pratt & Whitney, 2000]

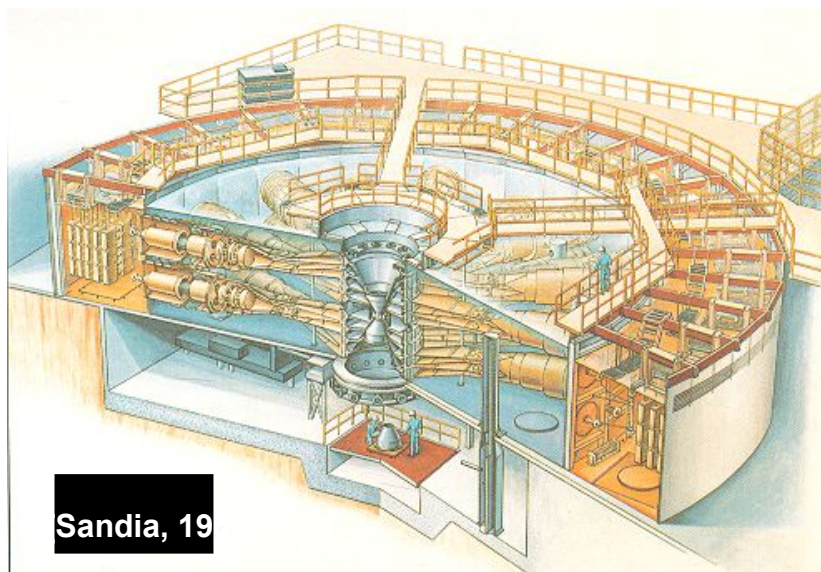
Common strategies exist for the middles of scientific reports

Parallel
Parts



Corel Corporation

Flow



Sandia, 19

Section headings should be descriptive and parallel

**Non-Parallel
Non-Descriptive**

**Parallel
Descriptive**

**Introduction
Background
Marx Generators
Line Pulse
Beam Generation
Transporting Beam
Pellets
Results
Conclusions**

Introduction

Past Designs for Particle Beam Fusion

New Design for Particle Beam Fusion
Charging Marx Generators
Forming Line Pulse
Generating Particle Beam
Transporting Particle Beam
Irradiating Deuterium-Tritium Pellets

Results of New Design

Conclusions and Recommendations

**When you divide a section into subsections,
all the pieces should be of the same pie**

New Design for Particle Beam Fusion

Charging Marx Generators

Generating Particle Beam

Producing Deuterium-Tritium Pellets



Organization is hidden when headings occur in a long list without secondary headings

Performance of the Solar One Receiver

Introduction

Steady State Efficiency

Average Efficiency

Start-Up Time

Operation Time

Operation During Cloud Transients

Panel Mechanical Supports

Tube Leaks

Conclusion

Performance of the Solar One Receiver

Introduction

Receiver's Efficiency

Steady State Efficiency

Average Efficiency

Receiver's Operation Cycle

Start-Up Time

Operation Time

Operation During Cloud Transients

Receiver's Mechanical Wear

Panel Mechanical Supports

Tube Leaks

Conclusion

Many journal articles follow a set organization named IMRaD



Introduction



Materials and Methods



Results

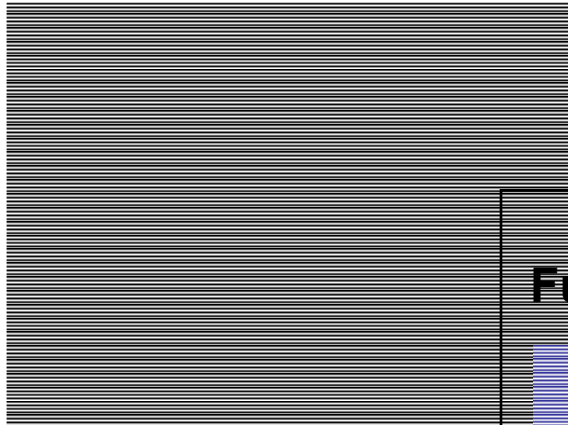


Discussion

In a strong ending, you analyze results and give a future perspective

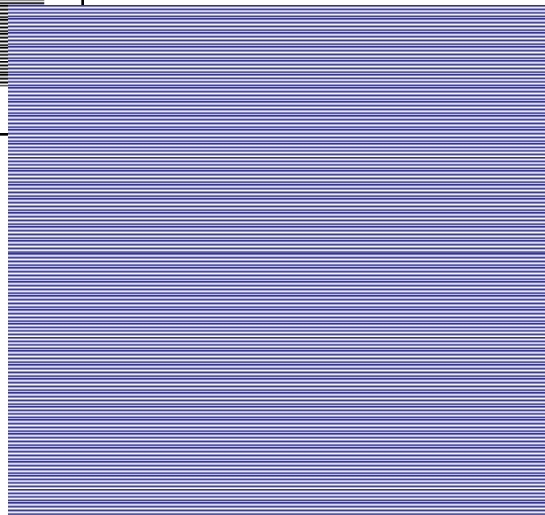
Conclusions

Analysis of Results



Analyze results from overall perspective

Future Perspective



*Several options:
Make recommendations
Discuss future work
Repeat limitations*

Appendix A

Concern About the Greenhouse Effect

For almost a hundred years, experts have been concerned with the increasing concentrations of gases such as carbon dioxide, methane, and nitrogen oxides in the earth's lower atmosphere. These gases are natural by-products of combustion. Figure A-1 illustrates the correlation between global temperature and carbon dioxide concentrations...

Use appendices to supply secondary or tangential information to primary readers

Appendix B

Project Stormfury

In 1961, the United States Weather Bureau and the Department of Defense (Navy) began a project to reduce the strength of hurricanes. The project, called Project Stormfury, uses cloud seeding, a process used to produce rainfall and reduce hail in thunderstorms. In Project Stormfury, silver iodide crystals, similar in structure to ice, are dispersed by airplanes in the upper reaches of cloud formations just outside the hurricane's eye where the winds are highest. Initial results showed that wind speeds decreased between 15–30% after seedings...

For secondary readers, use a glossary to define unfamiliar terms

Glossary

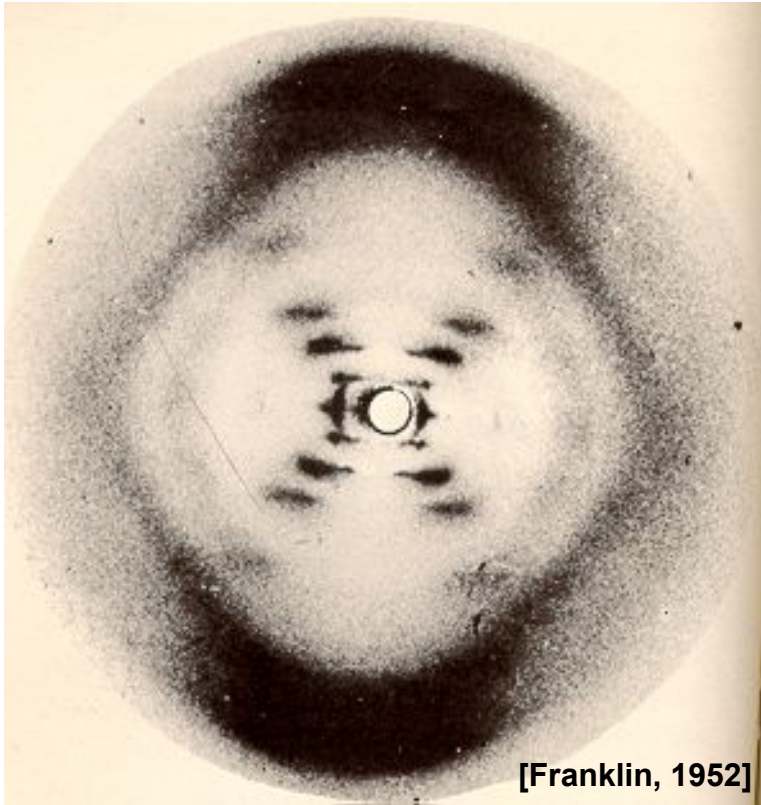
***burst point:* the exact point in space where an atomic bomb is detonated.**

***clear visibility:* a viewing range of twenty miles.**

***fallout:* the descent to the Earth's surface of radioactive particles from a cloud contaminated with the fission products of a nuclear explosion.**

***hypocenter:* the point on the earth's surface directly below the burst point; also called ground zero.**

Failing to cite the contribution of others can be a fatal flaw in your career



**James Watson surreptitiously
looked at Rosalind Franklin's work**



**Watson did not give enough
credit to Franklin**

Formatting Scientific Documents

Proceedings of
ASME TURBOEXPO 2000
May 8-11, 2000, Munich, Germany

2000-GT-0201

HIGH FREESTREAM TURBULENCE EFFECTS ON ENDWALL HEAT TRANSFER FOR A GAS TURBINE STATOR VANE

R.W. Radomsky* and K.A. Thole
Mechanical Engineering Department
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24060

ABSTRACT

High freestream turbulence along a gas turbine airfoil and strong secondary flows along the endwall have both been reported to significantly increase convective heat transfer. This study superposes high freestream turbulence on the naturally occurring secondary flow vortices to determine the effects on the flowfield and the endwall convective heat transfer. Measured flowfield and heat transfer data were compared between low freestream turbulence levels (0.0%) and combustion simulated turbulence levels (18.5%) that were generated using an active grid. These experiments were conducted using a scaled-up, first stage stator vane geometry. Infrared thermography was used to measure surface temperatures on a constant heat flux plate placed on the endwall surface. Laser Doppler velocimeter (LDV) measurements were performed of all three components of the mean and fluctuating velocities in the leading edge horseshoe vortex. The results indicate that the mean flowfields for the leading edge horseshoe vortex were similar between the low and high freestream turbulence cases. High turbulence levels in the leading edge-endwall junction were attributed to a vortex interaction for both the low and high freestream turbulence cases. While, in general, the high freestream turbulence increased the endwall heat transfer, low agreement was found to coincide with the regions having the most intense vortex motions.

INTRODUCTION

Along an airfoil airfoil surface, of varied convective heat transfer coefficients occur as a result of high turbulence developing in a gas turbine engine. The platform of an airfoil (endwall), a critical surface where durability can be an issue, also has high convective heat transfer levels with a complex topology. The complexity occurs from the secondary flows that develop in the form of vortices that sweep the platform surface. Both of these effects, high freestream turbulence effects on airfoil heat transfer and secondary flow effects on endwall heat transfer, have been discussed in the literature. When mixing from the flowfield in the combined effect of combustor level freestream turbulence and secondary flows on endwall heat transfer.

*Present address in United Technologies Research Center
41 Silver Lane
East Hartford, CT 06108

Turbulence measurements taken at the exit of a variety of gas turbine combustors have shown that the local τ_{max} can range between 8% and 40% (Goldstein, et al., 1983; Knott and McDiarmid, 1980; and Goshel, et al., 1993) with some indication that the integral length scale scales with the diameter of the dilution holes in the combustor (Moss, 1992). As these high levels progress through the downstream turbine vane passage, there is a production of turbulence resulting in high turbulent kinetic energy levels at the exit of the passage (Radomsky and Thole, 1999). The effect that these high turbulence levels have on the airfoil itself is to significantly increase the heat transfer along the leading edge and pressure side surfaces as well as move the transition location forward on the suction side surface.

The secondary flows previously mentioned take the form of a leading edge horseshoe vortex. This vortex splits into one leg that wraps around the suction surface and another leg that wraps around the pressure surface with the latter ultimately forming a passage vortex. As the flow progresses downstream, the flow is dominated by the passage vortex. Grainger and Russell (1994) identified, through flow visualization and surface heat transfer, that high convective heat transfer coefficients coincided with the most intense vortex action. Kang and Thole (1999) showed through flowfield and heat transfer measurements that the peak heat transfer coincided with the downstream legs of both the horseshoe vortex and passage vortex. The downstream leg of these vortices brings high speed freestream fluid towards the endwall and thus the boundary layer to ultimately increase the local heat transfer coefficients. As seen in several past endwall heat transfer studies (Chiarini, et al., 1980; and Boyle and Russell, 1990; Kang, et al., 1999) the peak heat transfer on the passage endwall escapes from the pressure side of the airfoil to the suction side of the adjacent airfoil in the passage vortex motion in that direction.

Although there have been a number of studies documenting high freestream turbulence effects on airfoil heat transfer and there have been a number of endwall flowfield and heat transfer studies, there are no studies documenting endwall heat transfer at combustor level freestream turbulence. The work presented in this paper investigates the effect that high turbulence has on endwall heat transfer. In particular, one of the regions having the highest heat transfer is the leading edge-endwall junction. These dimensional flowfield mea-

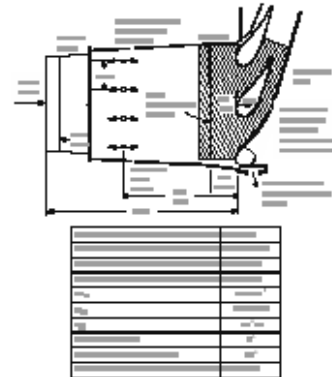


Figure 1. Schematic of corner test section containing the stator vane cascade.

An active-grid turbulence generator, described in detail by Radomsky and Thole (1999), was used to generate the high turbulence levels. The active grid consisted of vertical hollow square bars with jets impinging into the mainstream in both the upstream and downstream directions. The bars were 1.27 cm square with the jet holes having a diameter of 1.5 mm and vertically spaced 2.05 cm apart. These hollow bars were installed 88 bar widths upstream of the stator vane stagnation position or, in terms of vane coordinates at 1.9 chords in front of the stagnation position. A compressed air supply fed a plenum that supplied each of the bars. The turbulence generated from this active grid was 19.5% measured at 0.33 chords upstream of the vane stagnation location. The integral length scale at 0.33 chords upstream was $A_p = 0.12$ and was uniform across the span to within 4%. A detailed discussion of the inlet flow quality will be given later in the paper.

Flowfield Measurements

The flowfield was measured for a plane at the endwall-vane junction parallel with the incoming flow direction that intersects the stagnation location of the vane. This plane was chosen to compare with that previously reported by Kang, et al. (1999) at low turbulence conditions. The two-component backscatter fiber optic LDV system used in this study consisted of a 5 W laser used in conjunction with a TSI model 9200 Colohurst beam splitter. Velocity data was processed using TSI model IFA 755 Digital Beam Controller controlled using TSI's PIND software. All three velocity components (U , V , and W) were measured with a two-component laser Doppler velocimeter (LDV) positioned in two different orientations. A 750 micron focusing lens with a beam diameter was used at the end of the fiber optic probe to make measurements of the streamwise

(U) and pitchwise (W) components through the top endwall; and the streamwise (U) and spanwise (W) components through the sidewall. Coincident measurements were made through the sidewall to quantify the Reynolds shear stress, $\overline{u'v'}$. The probe volume length and diameter for the 750 micron lens with the beam expander were 0.85 mm and 72 microns. The data were corrected for velocity bias effects by applying radiance area weighting.

Endwall Heat Transfer Measurements

The heat transfer results for the high freestream turbulence conditions were measured in the same facility as for the low freestream turbulence conditions (Kang, et al., 1999). These measurements were obtained with a constant heat flux plate placed on the bottom endwall, as indicated by the cross-hatched area in Figure 1, surrounding the Styrofoam stator vane. The constant heat flux plate consisted of a 50 micron thick copper layer on top of a 75 micron thick kapton layer in which 25 micron thick incense burning elements were embedded in a serpentine pattern. This heater was placed onto a 1.9 cm thick wooden surface using double-sided tape. Just below the wood was a 2.54 cm thick 3-5 extruded Styrofoam board. The total heating area for the plate was 0.540 m² and the input power was adjusted to give a heat flux of 980 W/m². The lateral conduction was estimated to be less than 1% within the averaging spot size for the infrared camera. The top surface of the heater plate was painted black giving an emissivity of 0.94.

Surface temperature data was acquired using a calibrated infra-red camera (Inframetrics Model 700). The camera was calibrated in situ using type E infrared thermocouples that were painted black and placed on the heated surface. The calibration procedure was performed to obtain the correct plate emissivity and background temperature and insure a linear relationship between the infra-red camera measurements and the thermocouple reading over the required operating temperature range. To perform these measurements, the top endwall was replaced with a plate having 13 viewing ports in which an 11.43 cm diameter crystal flange window or, when not making measurements from that port, a leaner insert could be placed. Each endwall temperature readout from an average of 16 images and, based on an uncertainty analysis, it was determined that five of those 16-averaged images were enough to get a good average. Small positioning crosses were placed on the endwall to identify where each of the 13 images were relative to the turbine vane. An in-house processing routine allowed the 13 images to be assembled into one complete endwall temperature distribution. The infrared camera performed a spatial averaging over 0.37 cm and operated at a maximum viewing area of 21.5 cm by 16 cm represented by 256 by 256 pixels.

The input heat flux was corrected for radiation losses, which amounted to between 7-23 % of the input power, and conduction losses, which amounted to 1.7 -3.5 % of the input power. No correction was necessary regarding heat losses from conduction to the turbine vane itself because the vane was constructed using Styrofoam. Using the measured temperatures and the remaining convective heat flux, the heat transfer coefficients were computed and reported as Stanton numbers.

UNCERTAINTY ESTIMATES

The partial derivative and sequential perturbation methods, described by Moffat (1988), were used to estimate the uncertainties of the measured values. Uncertainties were calculated based on a 95% confidence interval. For each velocity component 15,000 data points were used to compare the mean and turbulence quantities whereas when coincidence data was acquired 20,000 data points were acquired. The relative of bias and precision uncertainties for the mean velocities were 5% while the precision of the raw velocities was 2.1% for u_{rms} , 1.7% for the v_{rms} and

In scientific writing, formats vary considerably to serve different situations

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Simulations using probabilistic distributions often represent a more realistic model in a number of situations, since producing and assembling parts to exactly the same dimension every time is not possible. An excellent example of statistical variation is found in gas turbine manufacturing where no manufactured part or clearance is ever at the exact nominal dimensions specified in the design. There is always a tolerance around the nominal value that results from the variation that is inherent to any manufacturing process. For a number of years, a wide range of industries have been using statistical models to control the quality of their product. More recently, industries have begun to formalize their statistical quality control, and have been putting forth a great deal of time and money to educate employees on the use of statistical methods. "Six Sigma" is an example of this formalization of statistical control, and is now in the forefront of many corporate training agendas.

Also presented with this work are methods to determine which level of reliability is most cost effective for an engine manufacturer. The cost-tolerance models used in this research are simple and intended to illustrate qualitative trends only. Lastly, the analysis methods presented in this work will be shown to be the foundation for future work that involves predicting the performance reliability of engines over time.

1.2 Approach

The approach used to conduct this research was modular in nature, with each successive step building upon the previous step. As such, this document is organized in a manner to walk the reader through each step in detail. This section gives a brief overview of each step that will later be discussed in more detail.

The first stage in being able to predict the performance reliability of an engine is simply being able to predict the performance of the engine with single point nominal inputs. Performance prediction models are common in aero-engine manufacturing industries and often provide very accurate predictions of engine performance. For variability-analysis methods such as those presented in this research, accurate

2

Proceedings of
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2000-GT-0201

HIGH FREESTREAM TURBULENCE EFFECTS ON ENDWALL HEAT TRANSFER FOR A GAS TURBINE STATOR VANE

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ABSTRACT

High freestream turbulence along a gas turbine airfoil and strong secondary flows along the endwall have both been reported to significantly increase convective heat transfer. This study explores high freestream turbulence on the airfoil's leading edge and secondary flows to determine the effects on the flowfield and the endwall convective heat transfer. Measured flowfield and heat transfer data were compared between low freestream turbulence levels (0.0%) and combustion-generated turbulence levels (19.5%) that were generated using an active grid. These experiments were conducted using a scaled-up, first stage stator vane geometry. Infrared thermography was used to measure surface temperatures on a constant heat flux plate placed on the airfoil surface. Laser Doppler velocimeter (LDV) measurements were performed at all three components of the mean and fluctuating velocities of the leading edge boundary layer. The results indicate that the mean flowfield for the leading edge boundary layer was similar between the low and high freestream turbulence cases. High turbulence levels in the leading edge-outflow plane were attributed to a vortex mechanism for both the low and high freestream turbulence cases. While, in general, the high freestream turbulence increased the endwall heat transfer, low temperatures were found to coincide with the regions having the most intense vortex motion.

INTRODUCTION

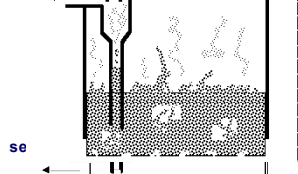
Along an airfoil surface, elevated convective heat transfer coefficients occur as a result of high turbulence levels along a curved surface in a gas turbine engine. The portion of an airfoil (endwall), a curved surface where heat transfer can be intense, also has high convective heat transfer levels with a complex topology. This complexity comes from the secondary flows that develop in the form of vortices that wrap the platform surface. Both of these effects, high freestream turbulence effects on airfoil heat transfer and secondary flow effects on endwall heat transfer, have been discussed in the literature. When raising freestream turbulence in the combustor, effects of combustion-generated turbulence and secondary flows on airfoil heat transfer.

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Turbulence measurements taken at the exit of a variety of gas turbine combustors have shown that the levels can range between 3% and 40% (Calkins, et al., 1983; Kocenas and McChark, 1986; and Ockel, et al., 1993) with some indications that the range is much wider with the diameter of the dilution holes in the combustor (Moss, 1992). As these high levels progress through the downstream turbine vane passage, there is production of turbulence resulting in high turbulent kinetic energy levels at the exit of the passage (Radomsky and Thole, 1999). The effect that these high turbulence levels has on the airfoil itself is to significantly increase surface transfer along the leading edge and pressure side surfaces as well as above the transition location forward on the suction side surface. The secondary flows previously mentioned take the form of a leading edge boundary vortex. This vortex often acts as a lag that wraps around the suction surface and another lag that wraps around the pressure surface with the latter ultimately forming a passage vortex. As the flow progresses downstream, the flow is dominated by the passage vortex. Greiger and Rowell (1984) identified, through flow visualization and surface heat transfer, the high convective heat transfer coefficients coincided with the most intense vortex action. King and Thole (1999) showed through flowfield and heat transfer measurements that the peak heat transfer coincided with the downstream legs of both the boundary vortex and passage vortex. The downstream leg of these vortices brings high speed flow from the endwall and thus the boundary layer to ultimately increase the local heat transfer coefficients. As seen in several past endwall heat transfer studies (Chenard, et al., 1986; and Boyle and Rowell, 1990; King, et al., 1999) the peak heat transfer on the passage outflow wraps from the pressure side of the airfoil to the suction side of the adjacent airfoil as the passage vortex moves in that direction. Although there have been a number of studies documenting high freestream turbulence effects on airfoil heat transfer and there have been a number of endwall flowfield and heat transfer studies, there are no studies documenting endwall heat transfer at combustor level freestream turbulences. The work presented in this paper investigates the effect that high turbulence has on airfoil heat transfer. In particular, one of the regions having the highest heat transfer is the leading edge-outflow process. Three-dimensional flowfield mea-

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The most effective combustion method is an atmospheric fluidized bed



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Figure 1

Fig. 1

fig. 1

Table 1

Table 1

table 1

equation 1

equation (1)

Eq. 1

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HIGH FREESTREAM TURBULENCE EFFECTS ON ENDWALL HEAT TRANSFER FOR A GAS TURBINE STATOR VANE

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ABSTRACT

High freestream turbulence along a gas turbine airfoil and strong secondary flows along the endwall have both been reported to significantly increase convective heat transfer. This study superimposes high freestream turbulence on the naturally occurring secondary flow vortices to determine the effects on the flowfield and the endwall convective heat transfer. Measured flow field and heat transfer data were compared between low freestream turbulence levels (0.6%) and combustor simulated turbulence levels (18.5%) that were generated using an active grid. These experiments were conducted using a scaled-up, first stage stator vane geometry. Infrared thermography was used to measure surface temperatures on a constant heat flux plate placed on the endwall surface. Laser Doppler velocimeter (LDV) measurements were performed of all three components of the mean and fluctuating velocities of the leading edge horseshoe vortex. The results indicate that the mean flowfields for the leading edge horseshoe vortex were similar between the low and high freestream turbulence cases. High turbulence levels in the leading edge-endwall junction were attributed to a vortex meandering for both the low and high freestream turbulence cases. While, in general, the high freestream turbulence increased the endwall heat transfer, low augmentation were found to coincide with the regions having the most intense vortex meandering.

INTRODUCTION

Along a turbine airfoil surface, elevated convective heat transfer coefficients occur as a result of high turbulence levels entering a combustor in a gas turbine engine. The platform of an airfoil (endwall), a critical surface where durability can be an issue, also has high convective heat transfer levels with a complex footprint. The complexity occurs from the secondary flows that develop in the form of vortices that sweep the platform surface. Both of these effects, high freestream turbulence effects on airfoil heat transfer and secondary flow effects on endwall heat transfer, have been discussed in the literature. What is missing from the literature is the combined effects of combustor level freestream turbulence and secondary flows on endwall heat transfer.

Turbulence measurements taken at the exit of a variety of gas turbine combustors have shown that the levels can range between 8% and 40% (Goldstein, et al., 1983; Kuetzler and McQuirk, 1989; and Coebal, et al., 1993) with some indication that the integral length scale scales with the diameter of the dilution holes in the combustor (Moss, 1992). As these high levels progress through the downstream turbine vane passage, there is a production of turbulence resulting in high turbulent kinetic energy levels at the exit of the passage (Radomsky and Thole, 1999). The effect that these high turbulence levels has on the airfoil itself is to significantly increase the heat transfer along the leading edge and pressure side surfaces as well as move the transition location forward on the suction side surface.

The secondary flows previously mentioned take the form of a leading edge horseshoe vortex. This vortex splits into one leg that wraps around the suction surface and another leg that wraps around the pressure surface with the latter ultimately forming a passage vortex. As the flow progresses downstream, the flow is dominated by the passage vortex. Gargler and Russell (1984) identified, through flow visualization and surface heat transfer, that high convective heat transfer coefficients coincided with the most intense vortex action. Kang and Thole (1999) showed through flow field and heat transfer measurements that the peak heat transfer coincided with the downward legs of both the horseshoe vortex and passage vortex. The downward leg of these vortices brings high speed freestream fluid towards the endwall and thus the boundary layer to ultimately increase the local heat transfer coefficients. As seen in several past endwall heat transfer studies (Gomez, et al., 1980; and Boyle and Stasul, 1990; Kang, et al., 1999) the peak heat transfer on the passage endwall sweeps from the pressure side of the airfoil to the suction side of the adjacent airfoil as the passage vortex moves in that direction.

Although there have been a number of studies documenting high freestream turbulence effects on airfoil heat transfer and there have been a number of endwall flowfield and heat transfer studies, there are no studies documenting endwall heat transfer at combustor level freestream turbulence. The work presented in this paper investigates the effect that high turbulence has on endwall heat transfer. In particular, one of the regions having the highest heat transfer is the leading edge-endwall junction. Three-dimensional flowfield mea-

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 - (170-330 MS) REDUCED PROBABILITY OF RELIABLE SECONDARY SEAL
 - (330-600 MS) HIGH PROBABILITY OF NO SECONDARY SEAL CAPABILITY
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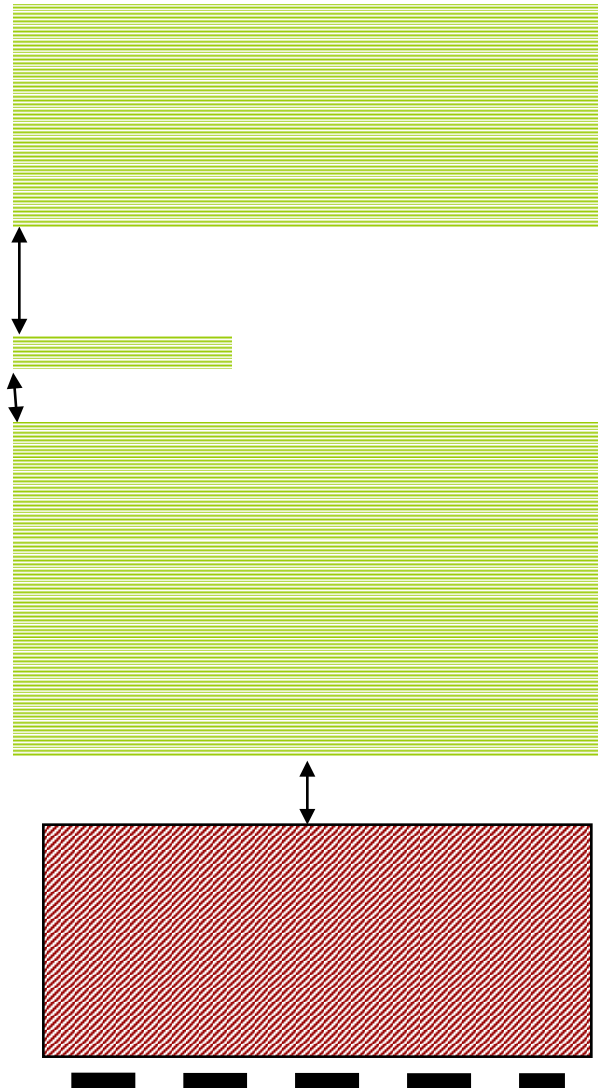
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