Naval Research Laboratory

Washington, DC 20375-5320

NRL/PU/5230--93-0241

NRL Report Formats

TIMOTHY D. CALDERWOOD

Publications Branch
Technical Information Division

December 10, 1993

REVIEWED AND APPROVED
December 1993

Peter H. Imhof
Head, Technical Information Division

CONTENTS

NRL REPORT FORMATS

INTRODUCTION

This *NRL Report Formats* publication has been extracted from the *Format and Style Guide* to provide authors and those who prepare reports a concise reference guide to technical report formats.

HOW TO USE THIS PUBLICATION

This publication is organized in the same way as an NRL Report, starting with the front cover and ending with an appendix at the back. Each component is illustrated with a sample and explanatory text on facing pages. Information is provided in a generic format so it can be used with any word processing or page layout software program.

Units of typographical measure are given in inches and points (where appropriate). Refer to the appendix for specific typographical information.

FEEDBACK

If you have any questions or suggestions, please give us a call. We solicit your feedback and input on the material presented in this document. In this way, any changes can be incorporated into this document without incurring the expense of reprinting the much larger *Format and Style Guide.* We encourage you to pass your comments to your local Site Technical Information Office as listed below:

NRL Washington—Fax (202) 404-8681			
Tim Calderwood	Publications Branch	Code 5230	(202) 767-2379
Kathy Parrish	Editorial Section	Code 5231	(202) 767-2782
Dora Wilbanks	CTC Section	Code 5234	(202) 767-2850
NRL Stennis—Fax (601) 688-4502			
Sherryl Liddell	Technical Information	Code 7035.3	(601) 688-4801
Linda Jenkins	Publications	Code 7035.3	(601) 688-5429
NRL Monterey—Fax (408) 656-4769			
Steve Bishop	Publications Section	Code 7524	(408) 656-4708
NRL Orlando—Fax (407) 857-5101			
Pat Ames	Technical Information	Code 5902.6	(407) 857-5101

FRONT COVER

Front covers are prepared by Site Technical Information Office production personnel to ensure uniformity of all NRL covers.

The thick-thin double rule on the cover and the information above it meet the requirements of the Navy Graphic Design Standards (SECNAVINST 5600.20) for official publications. The ruled line down the left margin and across the bottom arc design elements added by NRL.

Report numbers are assigned by the Site Technical Information Office. The site location and ZIP code are added to designate the location of the originator.

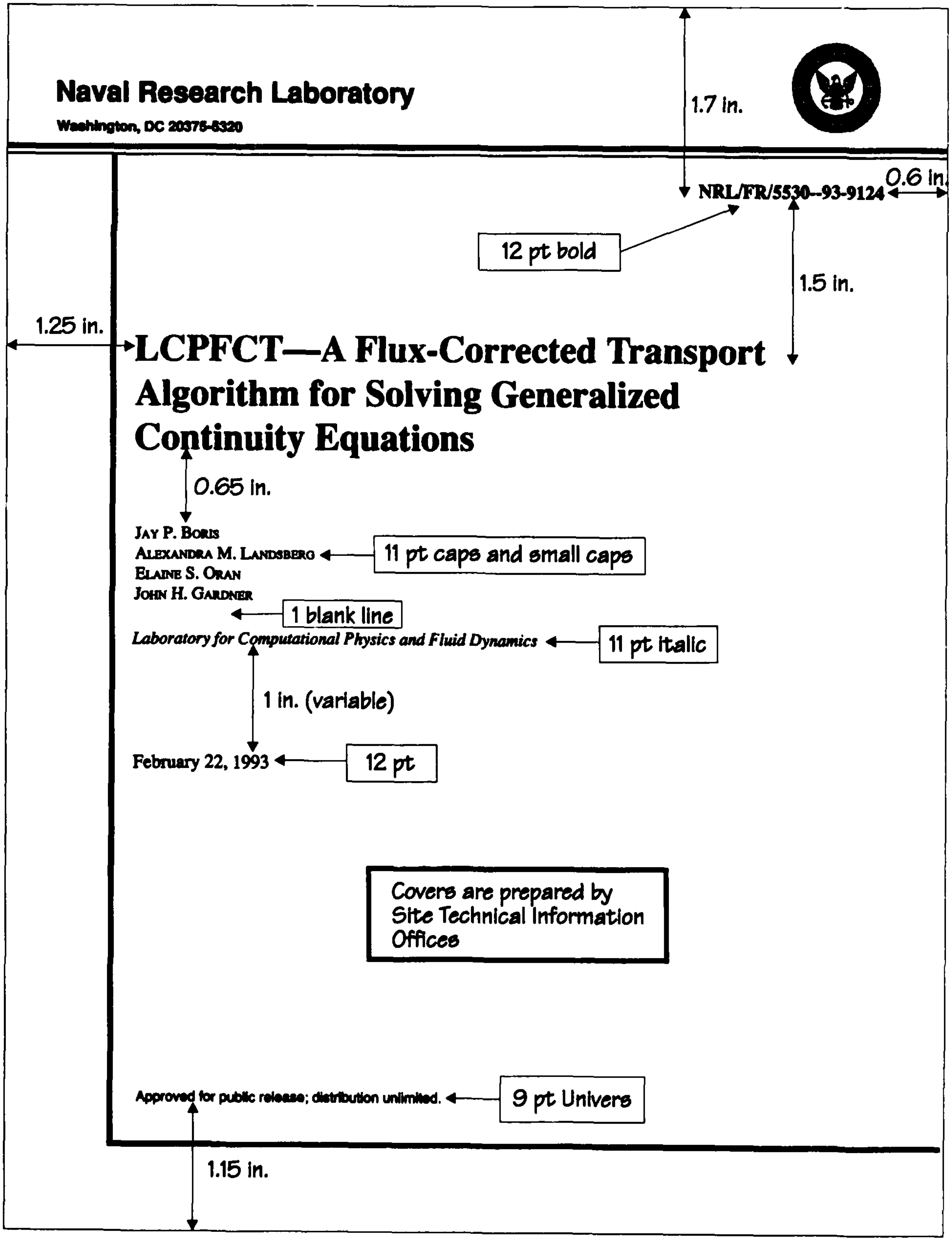


Fig. 1 — Front cover

REPORT DOCUMENTATION PAGE, SF 298

The REPORT DOCUMENTATION PAGE, SF 298, is the first right-hand page. It is part of the front matter and is numbered with a roman numeral lowercase "i." The SF 298 is completed in final form by the Site Technical Information Office.

For those who want to prepare a draft SF 298 in electronic form, the Site Technical Information Offices have this form available in WordPerfect 5.1 for DOS and PageMaker for the Mac. The text of the form is set in 9 pt CG Times. The page number is set in 11 pt CG Times and is centered at the bottom with a 0.5 in. margin.

We recommend that you let the production staff prepare this form for you to avoid unnecessary frustration. In addition, the Site Technical Information Offices are responsible for ensuring that the SF 298 is filled out correctly for submission to the Defense Technical Information Center (DTIC).

See the back of the SF 298 for instructions for what goes in each block. The number in Block 15 includes every page that has type on it.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget. Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 31, 1993	Interim Report

4. TITLE AND SUBTITLE

Electron Beam Quality Limitations and Beam Conditioning in Free Electron Lasers

5. FUNDING NUMBERS

PE - 9987N45J
PR - 128NJ90M1
WU - DN879-00

6. AUTHOR(S)

Philip Sprangle, B. Hafizi,* Glenn Joyce, and Philip Serafim†

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6183–93-7166

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Icarus Research, Bethesda, MD 20814
†Northeastern University, Boston, MA 02115

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The operation of free electron lasers can be severely limited by the axial velocity spread of the beam electrons. In this report we propose methods for reducing the axial velocity spread in electron beams by redistributing the electron energy via interaction with an axially symmetric, slow, TM waveguide mode. In the first method, the energy redistribution is correlated with the electrons' betatron amplitude, while in the second method it is correlated with the electrons' synchrotron amplitude. Reductions of more than a factor of 40 in the rms axial velocity spread have been obtained in simulations.

SF 298 forms are prepared by the
Site Technical Information Offices

14. SUBJECT TERMS

Free electron laser	Axial velocity spread
Emittance	Beam conditioning

15. NUMBER OF PAGES

14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

i

Fig. 2 — Report Documentation Page, SF 298

CONTENTS

The CONTENTS page is set up as shown in the sample. There is no header line on this page.

Margins—1st Page

	Inches	Points
Top	2	144
Bottom	0.75	54
Left	1	72
Right	1	72

Margins—Following Pages

	Inches	Points
Top	1	72
Bottom	0.75	54
Left	1	72
Right	1	72

Fonts

Title	**CG TIMES BOLD 12 PT FULL CAPS**
Text	CG Times 11 pt
Page numbers	CG Times 11 pt

Double space between levels of headings. Limit the number of headings to two levels in the contents pages. (Three may be used in exceptional cases.)

Page Numbers

Text Items

Individual text entries indicate the pages on which they are found in the body of the text. The page numbers are placed flush right with dot leaders.

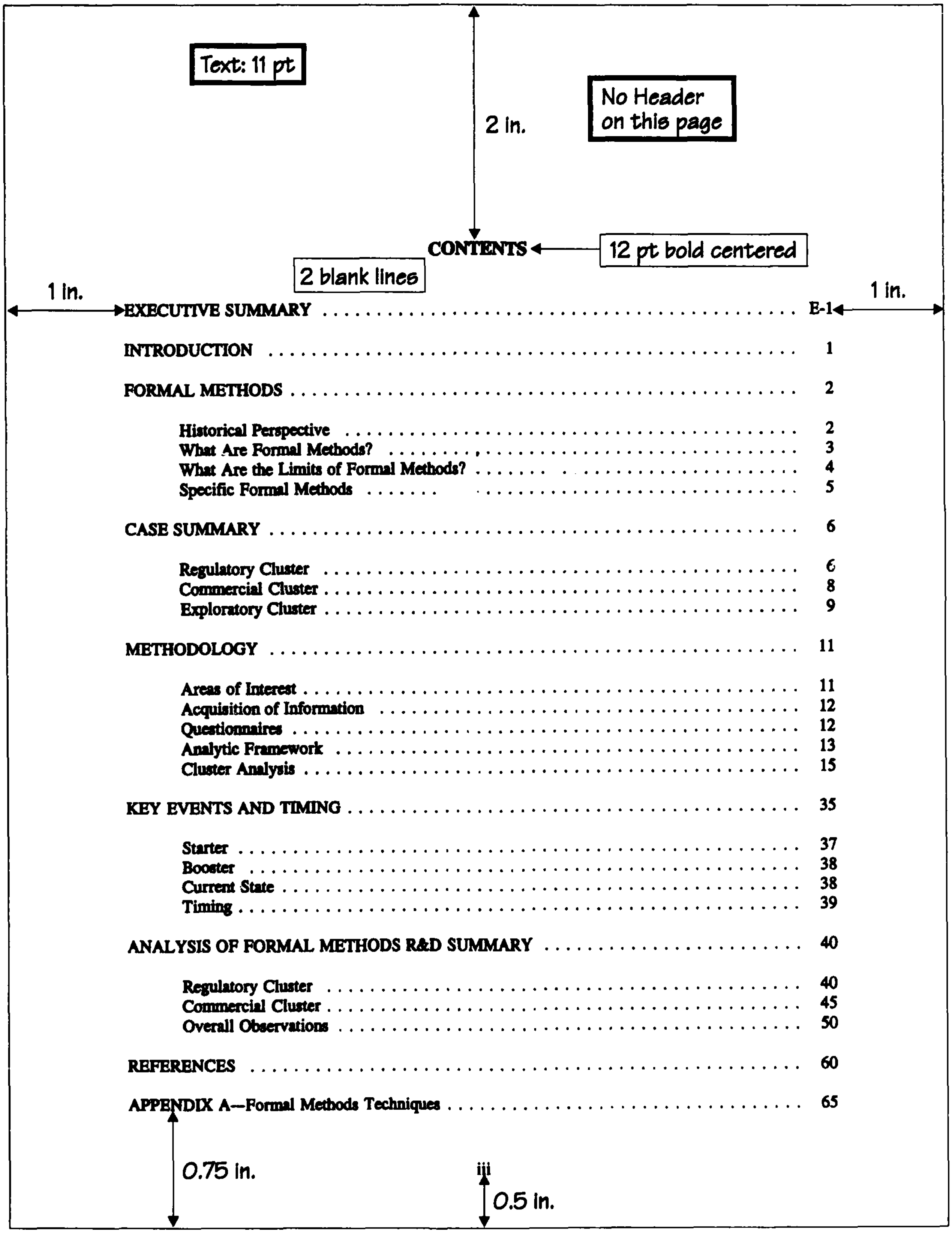
Page

The CONTENTS, as part of the front matter, are numbered with lowercase roman numerals beginning with iii.

LISTS OF FIGURES AND TABLES

Lists of figures and tables are generally not used. However, if the report contains a large number of figures and/or tables, such a listing might be desirable. These lists are given the centered titles of FIGURES and TABLES. They immediately follow the CONTENTS page(s).

If both lists are used, they do not have to be on separate pages; use two blank lines to separate them.



CONTENTS

iii

Fig. 3 — Contents

EXECUTIVE SUMMARY

The EXECUTIVE SUMMARY (if used) follows the CONTENTS and precedes the first page of text of the body of the report. The EXECUTIVE SUMMARY is set up as shown in the sample.

Margins—1st Page

	Inches	Points
Top	2	144
Bottom	0.75	54
Left	1	72
Right	1	72

Margins—Following Pages

	Inches	Points
Top	1	72
Bottom	0.75	54
Left	1	72
Right	1	72

Fonts

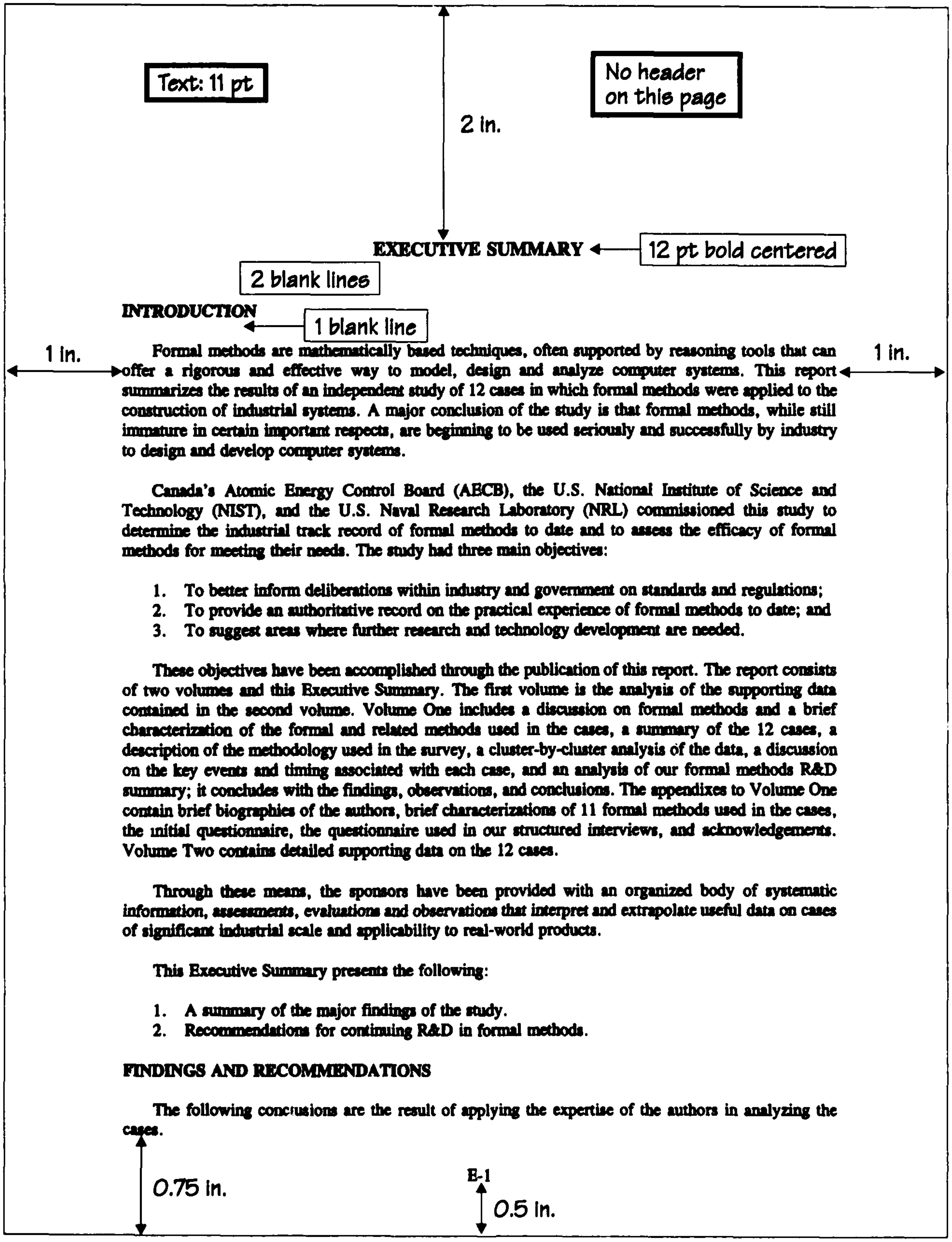
Title	**CG TIMES BOLD 12 PT FULL CAPS**
Text	CG Times 11 pt
Headings	See Regular Text Page sample (page 10).
Page numbers	CG Times 11 pt

Page Numbers

The EXECUTIVE SUMMARY is numbered with compound numbers beginning with E-1.

Headers and Footers

There are no headers or footers on any EXECUTIVE SUMMARY page(s).



EXECUTIVE SUMMARY

INTRODUCTION

Formal methods are mathematically based techniques, often supported by reasoning tools that can offer a rigorous and effective way to model, design and analyze computer systems. This report summarizes the results of an independent study of 12 cases in which formal methods were applied to the construction of industrial systems. A major conclusion of the study is that formal methods, while still immature in certain important respects, are beginning to be used seriously and successfully by industry to design and develop computer systems.

Canada's Atomic Energy Control Board (AECB), the U.S. National Institute of Science and Technology (NIST), and the U.S. Naval Research Laboratory (NRL) commissioned this study to determine the industrial track record of formal methods to date and to assess the efficacy of formal methods for meeting their needs. The study had three main objectives:

1. To better inform deliberations within industry and government on standards and regulations;
2. To provide an authoritative record on the practical experience of formal methods to date; and
3. To suggest areas where further research and technology development are needed.

These objectives have been accomplished through the publication of this report. The report consists of two volumes and this Executive Summary. The first volume is the analysis of the supporting data contained in the second volume. Volume One includes a discussion on formal methods and a brief characterization of the formal and related methods used in the cases, a summary of the 12 cases, a description of the methodology used in the survey, a cluster-by-cluster analysis of the data, a discussion on the key events and timing associated with each case, and an analysis of our formal methods R&D summary; it concludes with the findings, observations, and conclusions. The appendixes to Volume One contain brief biographies of the authors, brief characterizations of 11 formal methods used in the cases, the initial questionnaire, the questionnaire used in our structured interviews, and acknowledgements. Volume Two contains detailed supporting data on the 12 cases.

Through these means, the sponsors have been provided with an organized body of systematic information, assessments, evaluations and observations that interpret and extrapolate useful data on cases of significant industrial scale and applicability to real-world products.

This Executive Summary presents the following:

1. A summary of the major findings of the study.
2. Recommendations for continuing R&D in formal methods.

FINDINGS AND RECOMMENDATIONS

The following conclusions are the result of applying the expertise of the authors in analyzing the cases.

E-1

Fig. 4 — Executive Summary

FIRST PAGE OF TEXT

The first page of text is different from the succeeding text pages. The page number for only the first page is centered 0.5 in. from the bottom and is set in 11 pt CG Times using an arabic "1." (Page numbers on succeeding pages are contained in the headers.)

Margins—1st Page

	Inches	Points
Top	2	144
Bottom	0.75	54
Left	1	72
Right	1	72

Fonts

Title	**CG TIMES BOLD 12 PT FULL CAPS**
Text	CG Times 11 pt
Heading 1	**CG TIMES BOLD 11 PT FULL CAPS (FLUSH LEFT)**
Heading 2	**CG Times Bold 11 pt Initial Caps (Flush Left)**
Heading 3	*CG Times 11 pt Italic Initial Caps (Flush Left)*
Heading 4	**CG Times Bold 11 pt Initial Caps Indented**
Heading 5	CG Times 11 pt Indented Initial Caps—Run in with paragraph.
Heading 6	CG Times 11 pt Indented initial cap of 1st word—Run in with paragraph.

Header

There is no header on the first page of text.

Footer

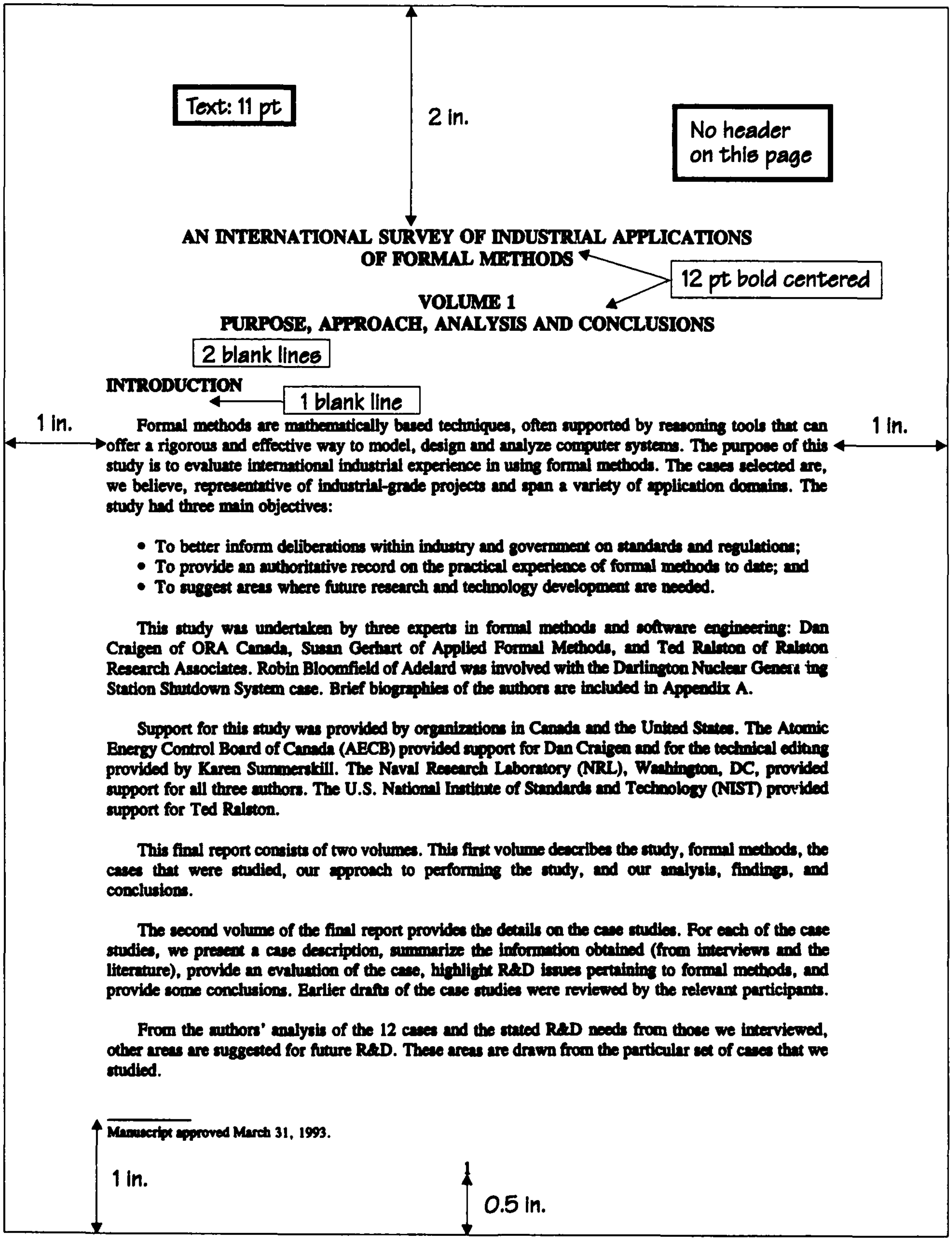
The "Manuscript approved [date]" footer appears at the bottom of the first page of text. It is preceded by a 0.007 in. (0.5 pt) thick horizontal line. This line is 0.75 in. (54 pt) long followed by a hard return. The text is 9 pt CG Times flush left under the line and is followed by two hard returns. Turn this footer off after page 1 for the remainder of the document.

The "Manuscript approved [date]" is taken from the Publication Approval Form and is the date the division superintendent signed off on the manuscript.

Vertical Spacing

There are two blank lines between the title and the start of the text. There is one blank line between paragraphs.

There is one blank line between headings 1, 2, 3, and 4 and the text following these headings. Headings 5 and 6 have the text begin on the same line right after the heading. Figure 6 shows examples of headings 1 through 5. Figure 6 shows examples of headings 1 through 5.



AN INTERNATIONAL SURVEY OF INDUSTRIAL APPLICATIONS OF FORMAL METHODS

VOLUME 1
PURPOSE, APPROACH, ANALYSIS AND CONCLUSIONS

INTRODUCTION

Formal methods are mathematically based techniques, often supported by reasoning tools that can offer a rigorous and effective way to model, design and analyze computer systems. The purpose of this study is to evaluate international industrial experience in using formal methods. The cases selected are, we believe, representative of industrial-grade projects and span a variety of application domains. The study had three main objectives:

- To better inform deliberations within industry and government on standards and regulations;
- To provide an authoritative record on the practical experience of formal methods to date; and
- To suggest areas where future research and technology development are needed.

This study was undertaken by three experts in formal methods and software engineering: Dan Craigen of ORA Canada, Susan Gerhart of Applied Formal Methods, and Ted Ralston of Ralston Research Associates. Robin Bloomfield of Adelard was involved with the Darlington Nuclear Generating Station Shutdown System case. Brief biographies of the authors are included in Appendix A.

Support for this study was provided by organizations in Canada and the United States. The Atomic Energy Control Board of Canada (AECB) provided support for Dan Craigen and for the technical editing provided by Karen Summerskill. The Naval Research Laboratory (NRL), Washington, DC, provided support for all three authors. The U.S. National Institute of Standards and Technology (NIST) provided support for Ted Ralston.

This final report consists of two volumes. This first volume describes the study, formal methods, the cases that were studied, our approach to performing the study, and our analysis, findings, and conclusions.

The second volume of the final report provides the details on the case studies. For each of the case studies, we present a case description, summarize the information obtained (from interviews and the literature), provide an evaluation of the case, highlight R&D issues pertaining to formal methods, and provide some conclusions. Earlier drafts of the case studies were reviewed by the relevant participants.

From the authors' analysis of the 12 cases and the stated R&D needs from those we interviewed, other areas are suggested for future R&D. These areas are drawn from the particular set of cases that we studied.

Manuscript approved March 31, 1993.

Fig. 5 — First page of text

REGULAR TEXT PAGE, LEFT-HAND PAGE

The next two samples illustrate the setup for regular text pages following the first page of text.

Margins

	Inches	Points
Top	0.75	54
Bottom	0.75	54
Left	1	72
Right	1	72

Header for Left-Hand Pages

The header for left-hand pages contains the page number (flush left) and the last name(s) of the author(s) (flush right) followed by a hard return (or 3 pt to ensure descenders do not run into or touch horizontal line). NOTE: In WordPerfect 5.1 for DOS this is a hard return plus 1/72 in. (1 pt).

If there is one author, use the author's full name. If two or three authors, use their last names only. If there are more than three authors, use only the first author's name, followed by "et al." (example: Craigen et al.). Note that there is no comma in front of *et al.*

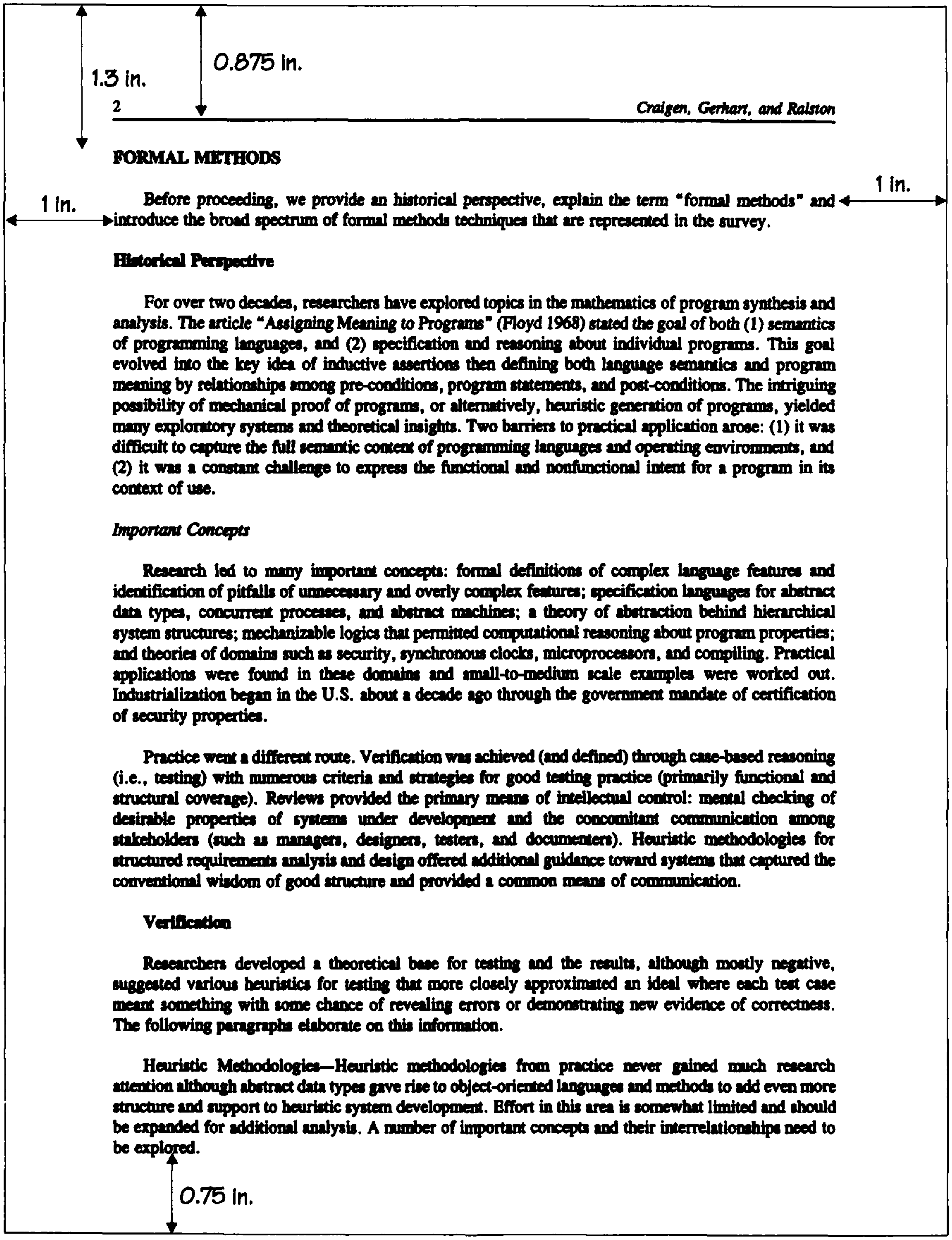
Text is 10 pt CG Times italic.

A full-width horizontal line is placed under the header text. This line is 0.014 in. (1 pt) thick and 6.5 in. long (468 pt). After the line should be a vertical space of 0.025 in. (18 pt).

Vertical Spacing

There are two blank lines between the title and the start of the text. There is one blank line between paragraphs.

There is one blank line between headings 1, 2, 3, and 4 and the text following these headings. Headings 5 and 6 have the text begin on the same line right after the heading.



2 *Craigen, Gerhart, and Ralston*

FORMAL METHODS

Before proceeding, we provide an historical perspective, explain the term "formal methods" and introduce the broad spectrum of formal methods techniques that are represented in the survey.

Historical Perspective

For over two decades, researchers have explored topics in the mathematics of program synthesis and analysis. The article "Assigning Meaning to Programs" (Floyd 1968) stated the goal of both (1) semantics of programming languages, and (2) specification and reasoning about individual programs. This goal evolved into the key idea of inductive assertions then defining both language semantics and program meaning by relationships among pre-conditions, program statements, and post-conditions. The intriguing possibility of mechanical proof of programs, or alternatively, heuristic generation of programs, yielded many exploratory systems and theoretical insights. Two barriers to practical application arose: (1) it was difficult to capture the full semantic content of programming languages and operating environments, and (2) it was a constant challenge to express the functional and nonfunctional intent for a program in its context of use.

Important Concepts

Research led to many important concepts: formal definitions of complex language features and identification of pitfalls of unnecessary and overly complex features; specification languages for abstract data types, concurrent processes, and abstract machines; a theory of abstraction behind hierarchical system structures; mechanizable logics that permitted computational reasoning about program properties; and theories of domains such as security, synchronous clocks, microprocessors, and compiling. Practical applications were found in these domains and small-to-medium scale examples were worked out. Industrialization began in the U.S. about a decade ago through the government mandate of certification of security properties.

Practice went a different route. Verification was achieved (and defined) through case-based reasoning (i.e., testing) with numerous criteria and strategies for good testing practice (primarily functional and structural coverage). Reviews provided the primary means of intellectual control: mental checking of desirable properties of systems under development and the concomitant communication among stakeholders (such as managers, designers, testers, and documenters). Heuristic methodologies for structured requirements analysis and design offered additional guidance toward systems that captured the conventional wisdom of good structure and provided a common means of communication.

Verification

Researchers developed a theoretical base for testing and the results, although mostly negative, suggested various heuristics for testing that more closely approximated an ideal where each test case meant something with some chance of revealing errors or demonstrating new evidence of correctness. The following paragraphs elaborate on this information.

Heuristic Methodologies—Heuristic methodologies from practice never gained much research attention although abstract data types gave rise to object-oriented languages and methods to add even more structure and support to heuristic system development. Effort in this area is somewhat limited and should be expanded for additional analysis. A number of important concepts and their interrelationships need to be explored.

Fig. 6 — Regular text page, left-hand page

REGULAR TEXT PAGE, RIGHT-HAND PAGE

A right-hand text page is shown in the sample. It differs from the left-hand text page only in its header.

Margins

	Inches	Points
Top	0.75	54
Bottom	0.75	54
Left	1	72
Right	1	72

Header for Right-Hand Pages

The header for right-hand pages contains a brief version of the report's title (flush left) and the page number (flush right) followed by a hard return (or 3 pt to ensure descenders do not run into or touch horizontal line). NOTE: In WordPerfect 5.1 for DOS this is a hard return plus 1/72 in. (1 pt).

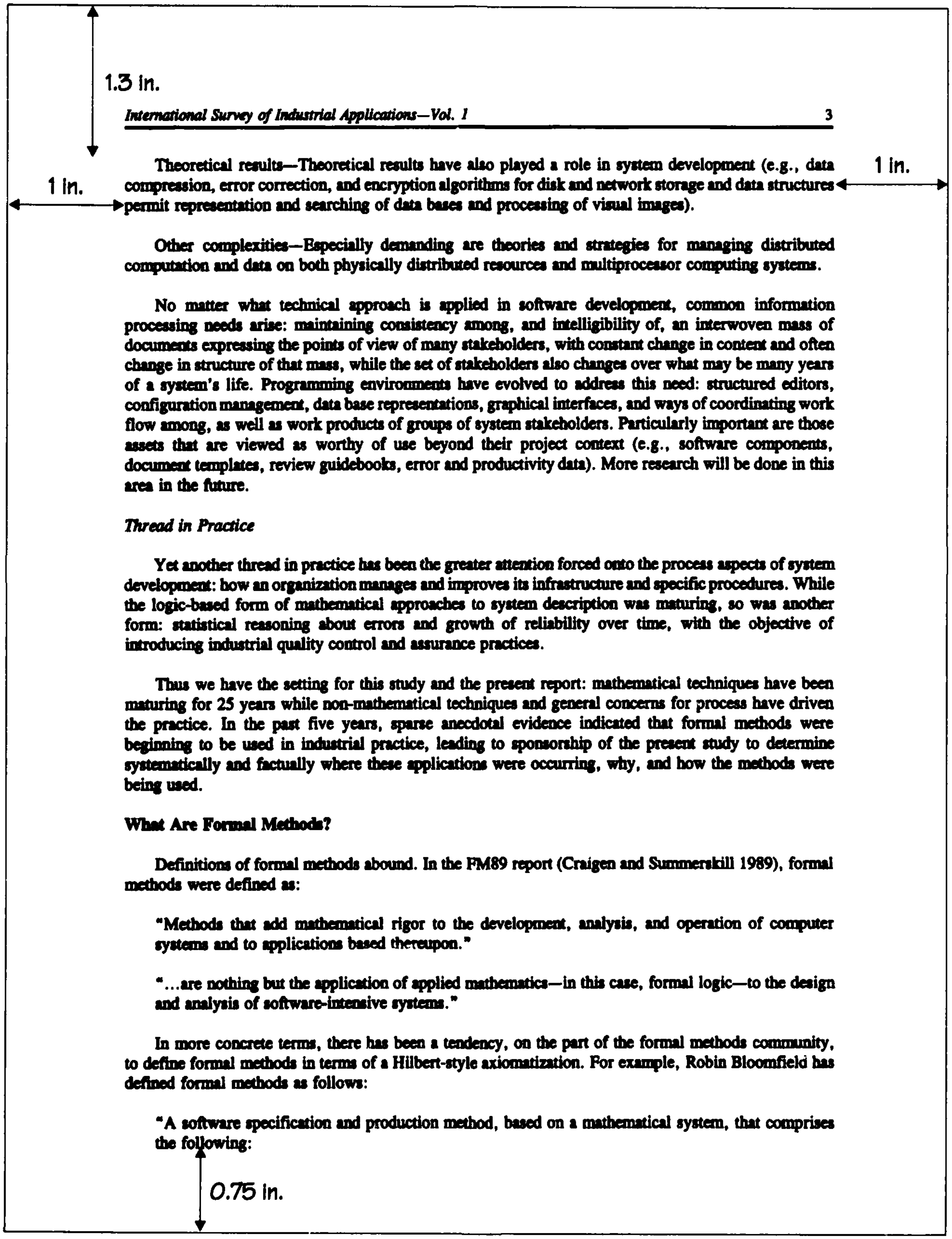
Text is 10 pt CG Times italic.

A full-width horizontal line is placed under the header text. This line is 0.014 in. (1 pt) thick and 6.5 in. long (468 pt). After the line should be a vertical space of 0.25 in. (18 pt).

Vertical Spacing

There are two blank lines between the title and the start of the text. There is one blank line between paragraphs.

There is one blank line between headings 1, 2, 3, and 4 and the text following these headings. Headings 5 and 6 have the text begin on the same line right after the heading.



International Survey of Industrial Applications—Vol. 1 3

Theoretical results—Theoretical results have also played a role in system development (e.g., data compression, error correction, and encryption algorithms for disk and network storage and data structures permit representation and searching of data bases and processing of visual images).

Other complexities—Especially demanding are theories and strategies for managing distributed computation and data on both physically distributed resources and multiprocessor computing systems.

No matter what technical approach is applied in software development, common information processing needs arise: maintaining consistency among, and intelligibility of, an interwoven mass of documents expressing the points of view of many stakeholders, with constant change in content and often change in structure of that mass, while the set of stakeholders also changes over what may be many years of a system's life. Programming environments have evolved to address this need: structured editors, configuration management, data base representations, graphical interfaces, and ways of coordinating work flow among, as well as work products of groups of system stakeholders. Particularly important are those assets that are viewed as worthy of use beyond their project context (e.g., software components, document templates, review guidebooks, error and productivity data). More research will be done in this area in the future.

Thread in Practice

Yet another thread in practice has been the greater attention forced onto the process aspects of system development: how an organization manages and improves its infrastructure and specific procedures. While the logic-based form of mathematical approaches to system description was maturing, so was another form: statistical reasoning about errors and growth of reliability over time, with the objective of introducing industrial quality control and assurance practices.

Thus we have the setting for this study and the present report: mathematical techniques have been maturing for 25 years while non-mathematical techniques and general concerns for process have driven the practice. In the past five years, sparse anecdotal evidence indicated that formal methods were beginning to be used in industrial practice, leading to sponsorship of the present study to determine systematically and factually where these applications were occurring, why, and how the methods were being used.

What Are Formal Methods?

Definitions of formal methods abound. In the FM89 report (Craigen and Summerskill 1989), formal methods were defined as:

> "Methods that add mathematical rigor to the development, analysis, and operation of computer systems and to applications based thereupon."

> "...are nothing but the application of applied mathematics—in this case, formal logic—to the design and analysis of software-intensive systems."

In more concrete terms, there has been a tendency, on the part of the formal methods community, to define formal methods in terms of a Hilbert-style axiomatization. For example, Robin Bloomfield has defined formal methods as follows:

> "A software specification and production method, based on a mathematical system, that comprises the following:

Fig. 7 — Regular text page, right-hand page

FIGURES

Location

Place figures as close as possible to where they are first mentioned. Figures that are full page in size are optically centered (a little above center). Avoid landscape and fold-in figures if possible. See your Site Technical Information Office for details on how to handle these special case figures.

Placement

Center the figure horizontally. Place it 0.5 in. (36 pt) below the baseline of the last line of text. There is 0.25 in. (18 pt) between the bottom of the figure and the baseline of the first line of the caption. Allow 0.5 in. (36 pt) between the baseline of the last line of the caption and the top of the next line of text. Labels and callouts are set in Helvetica and no smaller that 9 pt after final reduction.

Captions

Center the figure caption below the figure. The baseline of the first line of the caption is 0.25 in. (18 pt) below the bottom of the figure. Type is 9 pt CG Times. The first word is capitalized—the others are not (unless proper nouns). The caption does not end with a period (even if it is a complete sentence) unless it is followed by other sentences. If space below the figure is limited, captions may be placed beside the figure if there is room. The word ***figure*** is abbreviated as Fig. There is an em-dash between the figure number and the first word of the caption. An em-dash is equal in length to the type size.

Text Figures

Text figures are set in 10 pt CG Times. (See example on page 29.)

TABLES

Place tables within the text as close as possible to where they are first mentioned.

Placement

Center the table horizontally. Place it 0.5 in. (36 pt) below the last line of text, starting with the first line of the table title. Allow one hard return (0.17 in. or 12 pt) between the last line of the title and the top of the table. Allow 0.5 in. (36 pt) between the bottom of the table and the next line of text.

Titles

Center the table title 0.25 in. (18 pt) above the table. Type is 11 pt CG Times. Words in the title (except for articles) are initial caps. The title does not end with a period (even if it is a complete sentence) unless it is followed by other sentences. Place an em-dash between the table number and the first word of the title. An em-dash is equal in length to the type size. In this case, the em-dash is 10 pt long because the type is 10 pt in size. If the title is more than one sentence, only the first words are capitalized.

Size

Tables are set in 11 pt CG Times. Keep tables within the image area of the page (6.5 × 10 in.). To fit the area, tables may be set in a smaller type size (but no smaller than 8 pt).

PATTERN RECOGNITION ALGORITHM

Suppose we have a digitized $I \times J$ image g and that this is convolved with a mask or kernel k of size $(2N + 1) \times (2N + 1)$ to form an unscaled image h. The variables involved are defined by Table 1. The process of optimization, as shown in Fig. 1, comprises a search for the mask k_{opt} in a domain, or set of acceptable masks, K for which $f(G, k)$ is maximum.

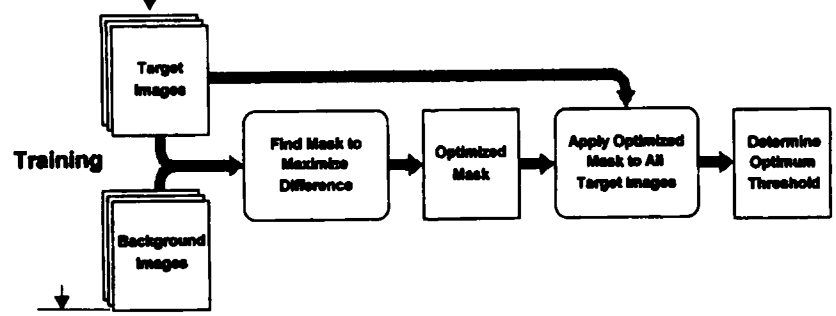
3 blank lines | 0.5 in. | 11 pt | 0.25 in.

Table 1 — Definitions of Variables

Object	Format	Class*	Domain†
Original Image	$g = g(i, j)$	$g, i, j \in \mathbb{Z}$	$0 \le g \le G$ $1 \le i \le I$ $1 \le j \le J$
Convolution Mask	$k = k(m, n)$	$k \in \mathbb{R}$ $m, n \in \mathbb{Z}$	$-K \le k \le K$ $-N \le m \le N$

*Z represents the set of all integers and R the set of all real numbers
†G is the maximum grey level in g, and K is the maximum absolute value for an element of k.

0.5 in.



0.25 in.

Fig. 1 — Schematic diagram of autonomous target-detection system ← 9 pt

0.5 in.

The convolution operation $h = g * k$ is commonly defined by

$$h(i, j) = \sum_{m=-N}^{N} \sum_{n=-N}^{N} g(i + m, j + n) \cdot k(m, n). \quad (1)$$

Where a mask is used as a feature detector (as in the current project), it is normal to apply the zero-sum constraint

$$\sum_{m=-N}^{N} \sum_{n=-N}^{N} k(m, n) = 0, \quad (2)$$

to prevent response to a uniformly gray image. In this case, we would expect the mean gray level for the convolved image to be zero so that in optimizing the mask k, we will be able to make use of the energy (or normalized variance) v of the convolved image.

Fig. 8 — Figure and table

APPENDIXES

Appendixes (if used) follow the main body of text and contain supplemental information. Although they stand alone, they must be mentioned in the text. They are set up in the same manner as the first page of text with two exceptions:

- The headers for left- and right-hand pages continue, except the first page of each appendix.

- There is no "Manuscript approved [date]" footer.

Margins—1st Page

	Inches	Points
Top	2	144
Bottom	0.75	54
Left	1	72
Right	1	72

Margins—Following Pages

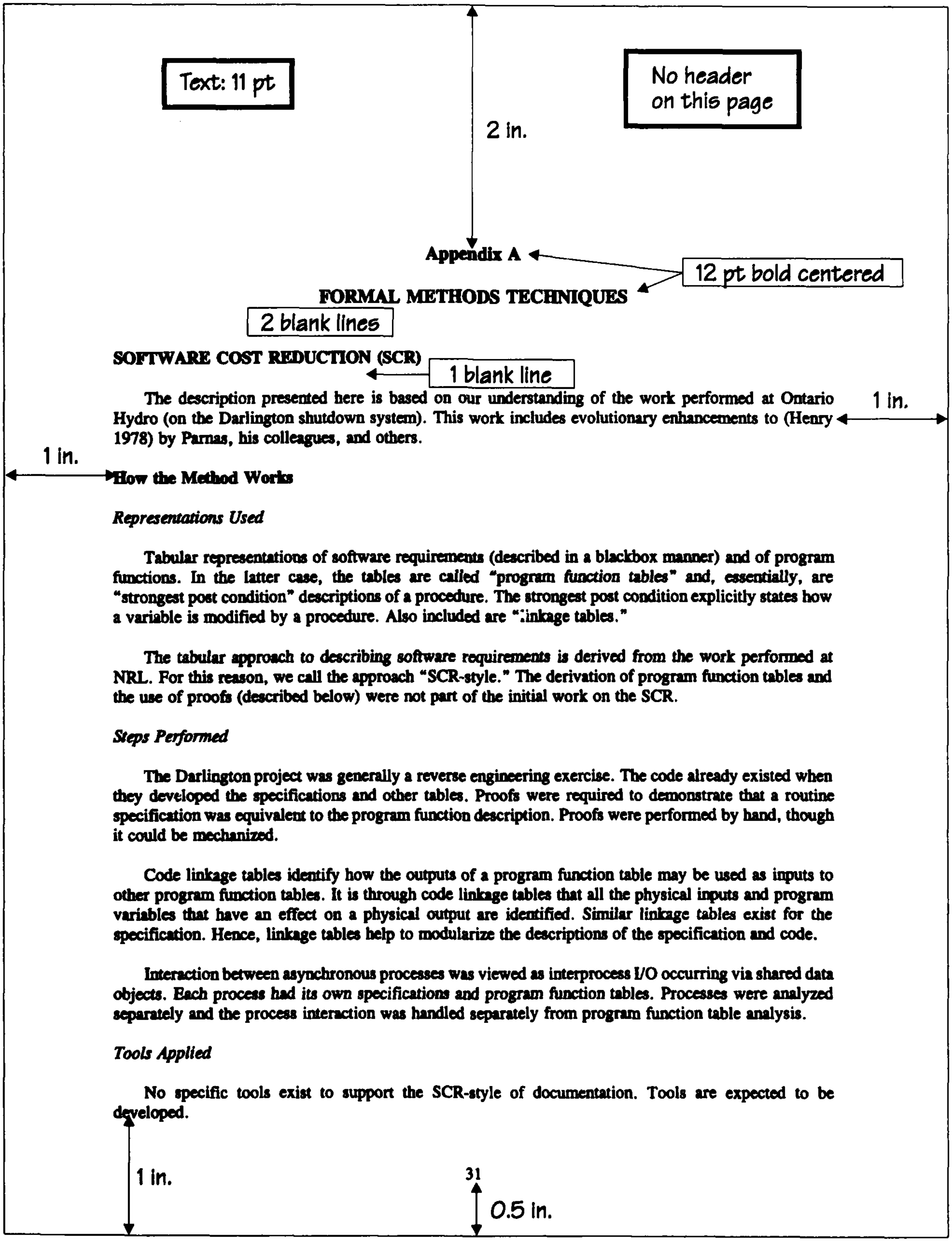
	Inches	Points
Top	1	72
Bottom	0.75	54
Left	1	72
Right	1	72

Title

The word "Appendix" on the first page of the appendix starts 2 in. from the top of the page. There is a blank line between the appendix designation and the title. Both are set in 12 pt bold CG Times with full caps.

Text

There are two blank lines between the last line of the title and the first line of the text. Text on the succeeding pages begins at the top of the page.



Appendix A

FORMAL METHODS TECHNIQUES

SOFTWARE COST REDUCTION (SCR)

The description presented here is based on our understanding of the work performed at Ontario Hydro (on the Darlington shutdown system). This work includes evolutionary enhancements to (Henry 1978) by Parnas, his colleagues, and others.

How the Method Works

Representations Used

Tabular representations of software requirements (described in a blackbox manner) and of program functions. In the latter case, the tables are called "program function tables" and, essentially, are "strongest post condition" descriptions of a procedure. The strongest post condition explicitly states how a variable is modified by a procedure. Also included are "linkage tables."

The tabular approach to describing software requirements is derived from the work performed at NRL. For this reason, we call the approach "SCR-style." The derivation of program function tables and the use of proofs (described below) were not part of the initial work on the SCR.

Steps Performed

The Darlington project was generally a reverse engineering exercise. The code already existed when they developed the specifications and other tables. Proofs were required to demonstrate that a routine specification was equivalent to the program function description. Proofs were performed by hand, though it could be mechanized.

Code linkage tables identify how the outputs of a program function table may be used as inputs to other program function tables. It is through code linkage tables that all the physical inputs and program variables that have an effect on a physical output are identified. Similar linkage tables exist for the specification. Hence, linkage tables help to modularize the descriptions of the specification and code.

Interaction between asynchronous processes was viewed as interprocess I/O occurring via shared data objects. Each process had its own specifications and program function tables. Processes were analyzed separately and the process interaction was handled separately from program function table analysis.

Tools Applied

No specific tools exist to support the SCR-style of documentation. Tools are expected to be developed.

31

Fig. 9 — Appendix

CLASSIFICATION MARKINGS

Covers and SF 298

Prepared by the Site Technical Information Office.

Every Page

The overall classification of the report is placed at the top and bottom of each page, as shown, centered in 14 pt bold Univers full caps. This requires modification of the headers and footers.

Headers

The headers are modified by adding two lines at the top of the header. The first line is for the page classification; the second line is a blank spacing line. The top margin is set at 0.5 in. (36 pt) for all pages.

Footers

The bottom margin is changed to 0.5 in. (36 pt) for all pages. A footer is set up to insert the report classification centered at the bottom margin of each page. The "Manuscript approved [date]" footer must be modified by adding two lines to the bottom. The bottom line is for the page classification; the next line up is a blank spacing line.

Contents

All headings and titles must have their classifications indicated in parentheses immediately following them.

Text

Enter a classification marking following the title and preceding every heading and paragraph.

If a paragraph is continued from the preceding page, the first line of text on the page must contain the classification marking of its paragraph, e.g., "((U) *paragraph continues*)."

Footnotes

Enter a classification marking following the footnote marker and before the footnote text.

Example: *(U) This is a footnote.

Each footnote receives a classification marking.

Figures

The classification of each figure is typed centered, full caps, CG Times 9 pt, 0.25 in. (18 pt) below the figure. The figure caption is placed 0.065 in. (5 pt) below the classification. The figure is marked even if it is unclassified.

Caption

The classification of the figure caption is placed after the em-dash following the figure number and just before the first word of the caption (e.g., Fig. 10 — (U) The caption).

Tables

The classification of each table is typed centered, full caps, 9 pt CG Times, 0.25 in. (18 pt) below the table.

Title

The classification of the table title is placed after the table number and just before the first word of the title, e.g., Table 2 — (U) The title.

Appendixes

All elements of an appendix are handled exactly the same as text pages. Although an unclassified appendix does not require headings or paragraph markings, it must carry the following statement in 12 pt bold, initial caps, centered above the title and appendix designation on the first page of the appendix.

(This Appendix Is Unclassified)

Blank Pages

Blank pages have the following statement centered on the page, "This Page Intentionally Left Blank." See Fig. 19. These blank pages are numbered.

CLASSIFICATION

Naval Research Laboratory

Washington, DC 20375-5320

NRL/FR/5541--93-9532
Copy of 20 Copies

Theory of Equipment Operation of the Model C Digital Message Device Group (U)

DOUGLAS R. STEINBAUM

Center for High Assurance Computing Systems
Information Technology Division

July 14, 1993

NOT RELEASABLE TO FOREIGN NATIONALS

Exempt from Distribution to Defense Technical Information Center in accordance with DoD Instruction 5100.38.

Classified by: NACSI 4003 Declassify on: Originating Agency Determination Required

Further dissemination only as directed by Commanding Officer, Naval Research Laboratory, Washington, DC 20375-5320; July 1993; or higher DoD authority.

CLASSIFICATION

Fig. 10 — Classified cover

CLASSIFICATION

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 31, 1993	Interim Report

4. TITLE AND SUBTITLE

Electron Beam Quality Limitations and Beam Conditioning in Free Electron Lasers (U)

5. FUNDING NUMBERS

PE - 9987N45J
PR - 128NJ90M1
WU - DN879-00

6. AUTHOR(S)

Philip Sprangle, B. Hafizi,* Glen Joyce, and Philip Serafim†

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6183--93-7166

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Icarus Research, Bethesda, MD 20814
†Northeastern University, Boston, MA 02115

12a. DISTRIBUTION/AVAILABILITY STATEMENT

[Select appropriate distribution statement from the back of the Publication Approval Form, HQ-NRL 5219/1 (REV. 12-93).]

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

(U) The operation of free electron lasers can be severely limited by the axial velocity spread of the beam electrons. In this report we propose methods for reducing the axial velocity spread in electron beams by redistributing the electron energy via interaction with an axially symmetric, slow, TM waveguide mode. In the first method, the energy redistribution is correlated with the electrons' betatron amplitude, while in the second method it is correlated with the electrons' synchrotron amplitude. Reductions of more than a factor of 40 in the rms axial velocity spread have been obtained in simulations.

14. SUBJECT TERMS

Free electron laser (U) Axial velocity spread (U)
Emittance (U) Beam conditioning (U)

15. NUMBER OF PAGES

14

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
CLASSIFICATION	CLASSIFICATION	CLASSIFICATION	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

i

CLASSIFICATION

Fig. 11 — Classified Report Documentation Page, SF 298

0.5 in.

CLASSIFICATION

CONTENTS (U)

iii

1 hard return

CLASSIFICATION

0.5 in.

Fig. 12 — Classified contents

CLASSIFICATION

EXECUTIVE SUMMARY (U)

(U) INTRODUCTION

(U) Formal methods are mathematically based techniques, often supported by reasoning tools that can offer a rigorous and effective way to model, design and analyze computer systems. This report summarizes the results of an independent study of 12 cases in which formal methods were applied to the construction of industrial systems. A major conclusion of the study is that formal methods, while still immature in certain important respects, are beginning to be used seriously and successfully by industry to design and develop computer systems.

(U) Canada's Atomic Energy Control Board (AECB), the U.S. National Institute of Science and Technology (NIST), and the U.S. Naval Research Laboratory (NRL) commissioned this study to determine the industrial track record of formal methods to date and to assess the efficacy of formal methods for meeting their needs. The study had three main objectives:

1. (U) To better inform deliberations within industry and government on standards and regulations;
2. (U) To provide an authoritative record on the practical experience of formal methods to date;
3. (U) To suggest areas where further research and technology development are needed.

(U) These objectives have been accomplished through the publication of this report. The report consists of two volumes and this Executive Summary. The first volume is the analysis of the supporting data contained in the second volume. Volume One includes a discussion on formal methods and a brief characterization of the formal and related methods used in the cases, a summary of the 12 cases, a description of the methodology used in the survey, a cluster-by-cluster analysis of the data, a discussion on the key events and timing associated with each case, and an analysis of our formal methods R&D summary; it concludes with the findings, observations, and conclusions. The appendixes to Volume One contain brief biographies of the authors, brief characterizations of 11 formal methods used in the cases, the initial questionnaire, the questionnaire used in our structured interviews, and acknowledgements. Volume Two contains detailed supporting data on the 12 cases.

(U) Through these means, the sponsors have been provided with an organized body of systematic information, assessments, evaluations and observations that interpret and extrapolate useful data on cases of significant industrial scale and applicability to real-world products.

(U) This Executive Summary presents the following:

1. (U) A summary of the major findings of the study.
2. (U) Recommendations for continuing R&D in formal methods.

(U) FINDINGS AND RECOMMENDATIONS

(U) The following conclusions are the result of applying the authors' expertise in analyzing the cases.

E-1

CLASSIFICATION

Fig. 13 — Classified Executive Summary

CLASSIFICATION

AN INTERNATIONAL SURVEY OF INDUSTRIAL APPLICATIONS OF FORMAL METHODS (U)

Volume 1
PURPOSE, APPROACH, ANALYSIS AND CONCLUSIONS (U)

(U) INTRODUCTION

(U) Formal methods are mathematically based techniques, often supported by reasoning tools that can offer a rigorous and effective way to model, design and analyze computer systems. The purpose of this study is to evaluate international industrial experience in using formal methods. The cases selected are, we believe, representative of industrial-grade projects and span a variety of application domains. The study had three main objectives:

- (U) To better inform deliberations within industry and government on standards and regulations;
- (U) To provide an authoritative record on the practical experience of formal methods to date; and
- (U) To suggest areas where future research and technology development are needed.

(U) This study was undertaken by three experts in formal methods and software engineering: Dan Craigen of ORA Canada, Susan Gerhart of Applied Formal Methods, and Ted Ralston of Ralston Research Associates. Robin Bloomfield of Adelard was involved with the Darlington Nuclear Generating Station Shutdown System case. Brief biographies of the authors are included in Appendix A.

(U) Support for this study was provided by organizations in Canada and the United States. The Atomic Energy Control Board of Canada (AECB) provided support for Dan Craigen and for the technical editing provided by Karen Summerskill. The U.S. Naval Research Laboratory (NRL), Washington, DC, provided support for all three authors. The U.S. National Institute of Standards and Technology (NIST) provided support for Ted Ralston.

(U) This final report consists of two volumes. This first volume describes the study, formal methods, the cases that were studied, our approach to performing the study, and our analysis, findings, and conclusions.

(U) The second volume of the final report provides the details on the case studies. For each of the case studies, we present a case description, summarize the information obtained (from interviews and the literature), provide an evaluation of the case, highlight R&D issues pertaining to formal methods, and provide some conclusions. Earlier drafts of the case studies were reviewed by the relevant participants.

(U) From the authors' analysis of the 12 cases and the stated R&D needs from those we interviewed, other areas are suggested for future R&D. These areas are drawn from the particular set of studied cases.

Manuscript approved March 31, 1993.

1
CLASSIFICATION

Fig. 14 — Classified first page of text

(U) CASE SUMMARY

(U) Twelve projects were chosen as the object of our study. These projects can be divided into three clusters: regulatory, commercial and exploratory. Regulatory cases exhibit safety- or security-critical attributes and thereby attract the attention of the standards communities and agencies, and the regulators who will license the product for use. Commercial cases are those cases that involve purely profit concerns. Finally, the exploratory cases are those cases where the organizations involved were investigating the potential utility of formal methods in their own settings.

(U) The cases are international, involving organizations in Canada, the United Kingdom, the United States, and continental Europe. Available resources did not permit the inclusion of cases from Asia or Australia.

(U) We believe that the cases collectively uncover many factors that are relevant to evaluating the efficacy, utility, and applicability of formal methods. The cases also demonstrate different uses of formal methods. For example,

- (U) "modelization," where formal languages (e.g., Z) are used to model systems;
- (U) demonstrating conformance of code with specifications;
- (U) demonstrating conformance of design with requirements; and
- (U) the application of mathematical reasoning to solve difficult conceptual problems.

(U) Finally, we believe that the cases encompass many of the anecdotal claims, both pro and con, regarding formal methods.

(U) In the remainder of this section, we present summaries of our 12 cases. The cases are introduced in the context of the clusters. Our analysis of the collection of cases will be based on these clusters. Throughout the report we will make use of abbreviations to identify the cases; these abbreviations are introduced with the name of the case. Figure 2 presents an idea of the size of the applications involved. Of course, "lines of code" is a rather superficial measure and must be viewed with caution.

(U) Regulatory Cluster

(U) Darlington: Trip Computer Software (DNGS)

(U) Ontario Hydro and AECL developed computer-controlled shutdown systems for the Darlington Nuclear Generating Station (DNGS). When difficulties arose in obtaining an operating license from the Atomic Energy Control Board of Canada (AECB), the Canadian regulator for nuclear generating stations, formal methods were applied to assure AECB that the software met requirements. The process was one of post-development mathematical analysis of requirements and code using Software Cost Reduction.

(U) The specifications, code and proofs require 25 three-inch binders for each of the two shutdown systems. While there is some discrepancy in the various papers on the amount of code for the two shutdown systems, the definitive word was that one of the shutdown systems (SDS1) has about 2500 lines of code.

(U) The use of the Software Cost Reduction approach finally convinced the AECB that the shutdown system was no longer a licensing impediment. The cases we investigated used a broad collection of formal

Fig. 15 — Classified regular text page, left-hand page

CLASSIFICATION

International Survey of Industrial Applications—Vol. 1 7

((U) *paragraph continues*)
methods. In Appendix B, we present summaries of the principal formal methods that are mentioned in the report. References for the various methods are included and our readers are directed to those references for in-depth presentations of the methods. Volume 2 of the Vienna Development Methodology symposium proceedings also includes tutorial presentations of a number of formal methods.

(U) Specific Formal Methods

(U) The cases we investigated used a broad collection of formal methods. In Appendix B, we present summaries of the principal formal methods that are mentioned in the report. References for the various methods are included and our readers are directed to those references for in-depth presentations of the methods. Volume 2 of the Vienna Development Methodology symposium proceedings also includes tutorial presentations of a number of formal methods.

(U) In Fig. 1, we associate the methods with the cases in which they have been used. Appendix B summarizes the methods. The cases are summarized in Section 3.

- Software Cost Reduction (SCR): Darlington Nuclear Generating Station (DNGS)
- B: SACEM
- Cleanroom Software Methodology: COBOL Structuring Facility (COBOL/SF)
- Formal Development Methodology (FDM): Token-Based Access Control System (TBACS)
- Gypsy Verification Environment (GVE): Multinet Gateway System (MGS)
- Hoare Logic: SACEM
- Occam and Communicating Sequential Processes (CSP): INMOS Transputer
- RAISE: Large Correct Systems (LaCoS)
- Hewlett-Packard Specification Language
- TCAS Methodology: Traffic Alert and Collision Avoidance System
- Z: SSADM Toolset, Tektronix oscilloscopes, INMOS Transputer

UNCLASSIFIED

Fig. 1 — (U) Formal methods used in surveyed cases

(U) Our summaries of the methods are divided into two parts: we discuss how the method works, and present some observations. We subdivide our discussion on how the method works by identifying the:

- Representations used: What are the underlying notations?
- Steps performed: How are the representations used?
- Tools applied: What tools are generally used?
- Roles involved: Who does what and what skill do they have?
- Artifacts produced: What are the major products that are documented?

(U) For our observations we describe what the method achieves and the limitations of the method. We also identify other techniques that are supported and required and identify the user community. The rest of the report provides detailed information concerning the data collection process and how it was analyzed.

CLASSIFICATION

Fig. 16 — Classified regular text page, right-hand page

CLASSIFICATION

(U) PATTERN RECOGNITION ALGORITHM

(U) Suppose we have a digitized $I \times J$ image g and that this is convolved with a mask or kernel k of size $(2N + 1) \times (2N + 1)$ to form an unscaled image h. The variables involved are defined by Table 1. The process of optimization, as shown in Fig. 1, comprises a search for the mask k_{opt} in a domain, or set of acceptable masks, $\mathbf{K}$ for which $f(G, k)$ is maximum.

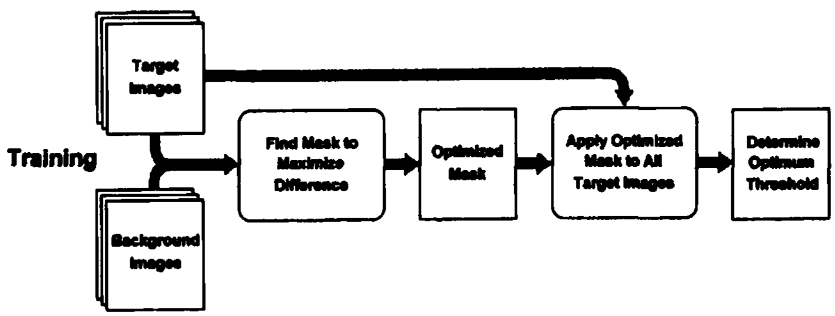
Table 1 — (U) Definitions of Variables

Object	Format	Class*	Domain†
Original Image	$g = g(i, j)$	$g, i, j \in \mathbf{Z}$	$0 \le g \le G$ $1 \le i \le I$ $1 \le j \le J$
Convolution Mask	$k = k(m, n)$	$k \in \mathbf{R}$ $m, n \in \mathbf{Z}$	$-K \le k \le K$ $-N \le m \le N$

*Z represents the set of all integers and R the set of all real numbers

†G is the maximum grey level in g, and K is the maximum absolute value for an element of k.

UNCLASSIFIED



UNCLASSIFIED

Fig. 1 — (U) Schematic diagram of autonomous target-detection system

(U) The convolution operation $h = g + k$ is commonly defined by

$$h(i, j) = \sum_{m=-N}^{N} \sum_{n=-N}^{N} g(i + m, j + n) \cdot k(m, n). \qquad (1)$$

Where a mask is used as a feature detector (as in the current project), it is normal to apply the zero-sum constraint

$$\sum_{m=-N}^{N} \sum_{n=-N}^{N} k(m, n) = 0, \qquad (2)$$

CLASSIFICATION

Fig. 17 — Classified figure and table

CLASSIFICATION

Appendix A

FORMAL METHODS TECHNIQUES (U)

(U) SOFTWARE COST REDUCTION (SCR)

(U) The description presented here is based on our understanding of the work performed at Ontario Hydro (on the Darlington shutdown system). This work includes evolutionary enhancements to (Henry 1978) by Parnas, his colleagues, and others.

(U) How the Method Works

(U) Representations Used

(U) Tabular representations of software requirements (described in a blackbox manner) and of program functions. In the latter case, the tables are called "program function tables" and, essentially, are "strongest post condition" descriptions of a procedure. The strongest post condition explicitly states how a variable is modified by a procedure. Also included are "linkage tables."

(U) The tabular approach to describing software requirements is derived from the work performed at NRL. For this reason, we call the approach "SCR-style." The derivation of program function tables and the use of proofs (described below) were not part of the initial work on the SCR.

(U) Steps Performed

(U) The Darlington project was generally a reverse engineering exercise. The code already existed when they developed the specifications and other tables. Proofs were required to demonstrate that a routine specification was equivalent to the program function description. Proofs were performed by hand, though it could be mechanized.

(U) Code linkage tables identify how the outputs of a program function table may be used as inputs to other program function tables. It is through code linkage tables that all the physical inputs and program variables that have an effect on a physical output are identified. Similar linkage tables exist for the specification. Hence, linkage tables help to modularize the descriptions of the specification and code. Interaction between asynchronous processes was viewed as interprocess I/O occurring via shared data objects. Each process had its own specifications and program function tables. Processes were analyzed separately and the process interaction was handled separately from program function table analysis.

(U) Tools Applied

(U) No specific tools exist to support the SCR-style of documentation. Tools are expected to be developed.

CLASSIFICATION

Fig. 18 — Classified appendix

CLASSIFICATION

This page

intentionally

left blank

34

CLASSIFICATION

Fig. 19 — Blank page in a classified report

Appendix

ADDITIONAL TYPOGRAPHICAL COMMENTS

PAPER SIZE 8.5 × 11 in.

FONTS

Use a roman typeface such as CG Times, Times Roman, or New Times Roman. The use of bold and italic fonts of these typefaces is required to match the specified format.

Title	**CG TIMES BOLD 12 PT FULL CAPS**
Text	CG Times 11 pt
Heading 1	**CG TIMES BOLD 11 PT FULL CAPS**
Heading 2	**CG Times Bold 11 pt Initial Caps**
Heading 3	*CG Times 11 pt Italic*
Heading 4	**CG Times Bold 11 pt Initial Caps Indented**
Heading 5	CG Times 11 pt Indented Initial Caps—Run in with paragraph.
Heading 6	CG Times 11 pt Indented initial cap of 1st word. Run in with paragraph.
Header A—Author's name(s)	*CG Times 10 pt italic*
Header B—Brief title	*CG Times 10 pt italic*
Figure captions	CG Times 9 pt
Table titles	CG Times 11 pt
Footer A—Manuscript approved	CG Times 9 pt

TABS AND INDENTS

Although tabs and indents may be adjusted to fit the requirements of the document, the following are recommended basic spacings for tabs and indents:

	Inches	Points
1st	0.273	20
2nd	0.438	32
3rd	0.921	66
4th	1.175	126
5th	2.0	144
6th	2.75	198

JUSTIFICATION	Full	
SPACES		
At end of sentence	Single space	
After a sequential number (e.g., 1., 2., 3., etc.)	Em-space	An em-space is equal to the type size in points. An em-space for 11 pt type is 11 pt wide, with no space before or after. (A double space is acceptable.)
DASHES		
Hyphenation	Use a regular hyphen or dash	
After a figure number in a caption	Em-dash	An em-dash is equal to the type size in points. An em-dash for 11 pt type is 11 pt wide. Put a space before and after the em-dash.
To show a range	En-dash	An en-dash is half of an em dash.
Double dashes (--)	Use an em-dash.	
PAGE NUMBERING		
Front matter	Lowercase roman numerals centered at bottom of page 0.5 in. from bottom edge set in 11 pt CG Times.	
Page 1 of text	Arabic one centered at bottom of page 0.5 in. from bottom edge set in 11 pt CG Times.	
All other text pages	Arabic numbers part of headers A and B set in 10 pt CG Times at outer margins: odd pages (header A) are flush right, even pages (header B) are flush left.	
EXECUTIVE SUMMARY	Arabic numbers starting with E-1 centered at bottom of page 0.5 in. from bottom edge set in 11 pt CG Times.	

MULTILINE FIGURE CAPTIONS

If a figure caption is two lines long, the second line is centered under the first caption line, *including the figure number*. If the figure caption is three or more lines long, the lines are typed full-figure width, same as the first line of the caption, *including the figure number*.

MULTILINE TABLE TITLES

If a table title is more than one line long, subsequent lines are centered under the complete first line of the title, *including the table number*.

PARAGRAPH NUMBERING

Paragraphs generally are not numbered. However, if paragraph numbering is required, then use the numeric decimal system with an em-space between the number and the heading or text.