Final Report

CONTINUED ADVANCEMENT OF THE PROGRAMMING LANGUAGE HAL TO AN OPERATIONAL STATUS

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This document represents the final report of a contract for the continued advancement of the programming language HAL to an operational status. The effort was sponsored by the National Aeronautics and Space Administration's Manned Spacecraft Center in Houston, Texas under Contract NAS-9-11944. It was performed by Intermetrics, Inc., Cambridge, Mass. under the technical direction of Mr. Daniel J. Lickly. The Technical Monitor for NASA/MSC was Mr. John Garman, FS/6.

The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.
1.0 TASK SUMMARY

The objectives and time duration of this contract were limited. Essentially, over the summer months of 1971 HAL was to be installed on the 360/75 at MSC, on-site support provided, users trained by class sessions, the compiler updated as necessary and experience gained with the language. The work was divided into two broad areas: maintenance and training, and advanced HAL development.

1.1 Task I: Maintenance and Training

Under this task, Intermetrics established a support systems programmer (Mr. Ronald Kole) at MSC within the Flight Software Section. Mr. Kole succeeded in solving some of the formidable problems associated with running at the RTCC under RTOS and transferred HAL from Intermetrics' 360/65 to MSC's 360/75. In addition, from time to time, necessary modifications originating in Cambridge and in Houston were incorporated at both sites and specifically, a general compiler-version update procedure was developed and implemented at MSC. The most significant modification was a redesign of the storage allocation algorithms, described in detail in Section 4.2 of this report.

Also as part of this task activity, 36 hours of training classes were conducted at MSC and the MIT Draper Laboratory. A total of approximately 50 people attended, including both government and industrial personnel.

Although no modifications were made which affected the HAL Specification or Guide documents, a new complete description of HALMAT, the intermediate code, was issued.

1.2 Task II: Advanced HAL Development

The objective of this development task was to increase the transferability of HAL to another host computer. The approach taken was to demonstrate that the compiler itself could be written in HAL. If this were accomplished then the entire compiler could be compiled on the 360 into FORTRAN and then the FORTRAN moved to almost any other large computer with only minor modifications. Toward this end a portion of the HAL compiler was coded in HAL and demonstrated to work on the 360/75 at the MIT Draper Laboratory. The portion selected exercised the bit and character handling features of HAL and indicates the feasibility of the approach.
2.0  HAL INSTALLATION AND ON-SITE SUPPORT

2.1  Installation

The HAL compiler and associated software were developed at the Harvard Computing Center in Cambridge, Massachusetts using a 360/65 running under OS/360 MVT Release 18. Transferability problems were encountered in establishing a usable HAL system at MSC. These problems may be broken down into two categories: (1) logistics and (2) internal software compatibility. Before the second set could even be recognized, the first had to be solved.

2.1.1  Logistics Problems

The logistics problems are the ones associated with the differences in operating procedures and at the systems' two installations. The preparation and submission of jobs at Harvard were done almost entirely through the Conversational Remote Batch Entry System (CRBE). The Harvard system was equipped with four IBM 1403 printers, each having a full PL/1 character set. The entire HAL system was maintained on a disk pack that was mounted by the operator when needed.

In contrast, the RTCC at MSC uses IBM 360/75 computers running a modified OS MVT which they call RTOS (Real Time Operating System). The RTOS version available during the June-September 1971 installation period corresponded roughly to OS/360 Release 18. The RTCC does not support the CRBE system, so all input submission was done via punched cards. This in itself was something of a problem since some pieces of the compiler and even some updates to the compiler were quite long. Also, the handling of cards and the chance of error in mixing up cards was considered less desirable than an on-line editing/submitting system like CRBE.

2.1.1.1  RTCC Limited Disk Space. The RTCC also has very limited available disk space. In fact, it is impossible to have a permanently saved disk on the system. Therefore, a reasonable way had to be found to give users access to the HAL compiler. The method settled on was to use a dump/restore tape. When a user wants to run something that is located on the HAL disk (known as HAL001 at the RTCC) he tells the operator of the requirement for this special disk. The operator must "restore" the disk from a tape before the user's actual job can run. This means that he must run a background utility to transfer the contents of a special tape to some existing disk on the
system so that any user programs requesting HAL001 will find the disk mounted. After the user's run finishes, the HAL001 disk is scratched to make room for perhaps some other user's restored disk.

This system works, but it puts all jobs that require HAL001 in a special class that is usually run only during the early morning hours. This obviously precludes any same-day turnaround as can sometimes be obtained with "non-special" device requirements. There is, however, an advantage that is gained indirectly through use of the dump/restore tape. Since it is not any one physical disk that is mounted to satisfy requests for HAL001, it is possible to have serial versions of the disk available as separate dump/restore tapes. The user need only specify which dump/restore tape he wants used to create HAL001. Since one HAL001 is the same to the system as any other, all of his Job Control Language will work no matter which dump/restore tape is used.

The more troublesome aspect of the dump/restore system is the creation of an updated HAL001 and getting that new version put onto a D/R tape. The method of updating is to submit the job that makes the desired changes, requesting that HAL001 be restored in the normal manner, but also requesting that the disk to which the restore will take place be completely erased first. The job is then run as a regular batch job. After the run is completed the operator is requested to "dump" HAL001 to some specified tape. This tape then becomes the updated restore tape.

The problem in this system can occur in many ways. The disk to be restored must be erased first. This is to assure that after the update run, HAL001 contains only the HAL001 files. The dump program that does the disk to tape transfer will copy anything that it finds on the disk, no matter where it originated. So failure to erase the disk, while not really causing any errors in the resulting D/R tape, makes the tape file very long. This also means that subsequent restores from the tape will take a much longer time. All of this degrades performance of the overall system. It is also possible, if an unerased disk is cluttered enough, to overflow one D/R tape which causes even more complications.

Another source of error is the possibility that the operator will forget to dump the disk at all. Since this is an operator controlled utility, the user gets no indication on his output if the disk was actually dumped. The only real way to tell is to submit another job the next day to see if the updates were indeed saved. There is no way of telling if the restore tape file is too big because of a non-erased disk, other than watching the restore take place and guessing whether the tape moves a reasonable distance. Once an oversized tape file has been created it is very difficult to get rid of the unwanted "garbage". Thus, the
dump/restore tape method of supplying users with a HAL system works fairly well from the user's viewpoint (although turnaround is probably adversely affected) but is error prone from the system maintenance point of view.

The real solution to the D/R problem is to eventually catalogue all of the HAL system components on the system library as is done with the other language translators. This could be done now, but such a method is even more difficult to update and maintain and should not be used for anything short of a non-changing, well established version of the system.

2.1.1.2 RTCC Limited Print Facility. One other source of frustration at the RTCC can be identified. The RTCC is basically designed to run space missions and not necessarily to support batch users. The main outputs of mission programs are real-time displays and telemetry. These require little hard copy I/O. The main output of the batch user is printout. Yet the RTCC has only one printer per machine with two others shared between all machines. The 360/65 at Harvard manages to keep four printers busy by itself. So it would seem that the faster model 75 would generate a print backlog with even the maximum of three printers attached. This did indeed seem to be the case at MSC. This print backlog, of course, results in reduced turnaround. The HAL compiler proper output requires a full PL/1 character set. At the RTCC there is only one printer that has the UCS (Universal Character Set) feature that can support a print set other than the standard limited FORTRAN 48 character one. All of the output that requires this special character set is spooled on tapes until such time as there is enough to make the mounting of the special print train worthwhile. That point is reached two or three times a day. So HAL print delays are generally even longer than those caused by the regular print backlog. A small point further slowing down the printing is that the print train that was used for HAL was a special one, known as the Philco train. Some characters used by HAL only appear once on this train. This delay in waiting for the single character to move to the correct print position makes a large reduction in the speed of the printers (a visual estimate would be 20 to 40% slower).

The necessity of mounting the special character set created another potential error situation. If for some reason the class of output was mis-written on the spool tape, or misread, the output might (and has on occasion) be printed on the Fortran print train. It is, of course, then unreadable. The net result of these operation dependent procedures was a 1 run per day situation at best. Some preliminary users experienced even longer delays.
2.1.2 Software Incompatibility

The second class of problems relating to implementing HAL at MSC concern the operating system peculiarities that are present in any system. The most significant difference between RTOS at MSC and OS/360 was the handling of core allocation. One part of the HAL compiler called the Submonitor was significantly affected by the RTOS scheme.

The Submonitor is an assembler language program whose purpose essentially is to provide an I/O interface with the operating system. It also has the task of obtaining a block of core storage into which the actual compiler machine code can be placed for execution. In the original version of the Submonitor at Harvard, the necessary core was requested by means of a GETMAIN macro instruction. The operating system then gave the Submonitor the requested core out of the remaining part of the task's region as specified in the REGION parameter. Thus, it was possible to use the region parameter to determine how much core was made available to run the compiler.

2.1.2.1 OS/360 Core Allocation. The standard OS scheduling algorithms keep jobs in a waiting queue until such time as there is available in the machine, enough core in a contiguous block to satisfy the job's REGION request. Then the job is started and is free to do whatever it wants with its core. This block of contiguous core is reserved for the one task, even if the task uses only a small part of it. Thus, if an adequate REGION parameter is supplied, the Submonitor is guaranteed the availability of the core it needs to run the compiler. The Submonitor, in fact, makes maximum use of the entire available core by using a form of the GETMAIN Macro instruction that gives the operating system a minimum and maximum value of acceptable core regions. The maximum is set very high so that the operating system, in trying to come as close as possible to the maximum requested allocates all of the core remaining in the Submonitor's region.

2.1.2.2 RTOS Core Allocation. RTOS, however, does not make a job wait until the requested REGION is available in a contiguous block. It waits only until the sum of all free core in the system meets or exceeds the requested REGION. In fact, the decision of which jobs to run at any one time is based on a 125% allocation of core on the assumption that not all jobs will require their entire region at the same time. So in the case of the HAL compiler which requires about 4K bytes of core,
the operating system will load and execute the Submonitor as soon as there is 4K contiguous core available and enough other free core to satisfy the rest of the specified REGION parameter (this is usually 300K for HAL). The Submonitor then immediately issues a GETMAIN for the remaining core. This is where the operating system differences cause problems.

Under RTOS, a GETMAIN of the original form used at Harvard causes the operating system to put the Submonitor task into a wait state until the maximum of the minimum/maximum pair is available. For a large maximum this never happens and the job must eventually be cancelled by the operator.

2.1.2.3 Some Solutions. The first attempt to fix this was made by allowing the user to specify in his JCL the minimum and maximum values to be used in the GETMAIN request instead of the Submonitor's default values. This approach will apparently work for smaller programs, but for larger programs, there seems to be some system prescribed limit to the amount of core that can be obtained in this way. The Submonitor was never able to obtain more than 262,144 (or $2^{18}$) bytes of core. This is not enough to run the compiler and another method was needed.

The second method was to change the type of GETMAIN to one that requested a single specific size piece of core. The user was given the ability to specify this number through a keyword in his JCL. This system partially solved the problem. It was possible to obtain the correct amount of core this way, but another problem persisted. Even though RTOS could guarantee the existence of 300K bytes of free core, it could not guarantee how this core was divided up as could the regular OS. It was possible for the Submonitor to go into a wait state while the operating system tried to supply its contiguous core requirement. Under the right circumstances, this might take an hour or more. Whenever a task goes into the wait state, RTOS monitors how long it stays there. After some length of time RTOS begins sending the operator messages informing him of the lack of progress of the task. The operator makes the decision on the length of time the task is allowed to wait. After he gets tired of seeing the periodic messages, he usually cancels the job. The problem with this method is that the operator is never told why the job is waiting; it may be waiting because of some programmer error. He really has no chance to evaluate the situation.

The next step taken toward insuring a successful run was to take the wait for core out of the running Submonitor and put it in the pre-execution allocation. This simply meant doing away with the GETMAIN and giving the Submonitor a built-in
storage area big enough to run HAL. Under this system, the Submonitor became about 300K bytes long. This forced the operating system to find the 300K in a contiguous region before it could even load the Submonitor. As before, it was still possible for the available core to total more than 300K and yet not have 300K contiguous, but now the operator got a message saying "JOBXXX AWAITING A REGION". In this way the operator was informed of the real cause for the delay and was more willing to let the job wait for the core to become available.

Although the probability of getting a job to run has been increased, it is still possible for the job to be cancelled when it was the only user job in the system and was still unable to get its core. This happens when there are "backround" utilities running. Although they are termed "backround", they still compete for core like any other job on the system and it is possible for them to tie up core in such a way that a HAL job will not run even though it appears to be all alone on the system.

One small drawback to this final state of the Submonitor is that it is no longer possible to use the REGION parameter, or any user keywords to limit the size of the available core. This is not considered much of a handicap since the size of the HAL compiler is quite stable and is expected to remain so.

There is an alternate approach to solving the core lockout problem. This would involve a redesign of the HAL compiler structure to give it a scatter loadable attribute. If this were done, the required core would not need to be contiguous; several smaller contiguous areas would be requested. The probability of finding these smaller areas would be greater than the present system. There would, however, still be a finite chance that even these smaller regions would not all be available. The situation is such that the more the core requirement is split up, the more chance there is that the resulting smaller pieces will be found. More pieces of code, however, require much more overhead to maintain. Also, the redesign of the HAL code to allow such a split would be a difficult job that would not further the goal of producing a better overall compiler. The frequency of run failures under the present system is very low and sporadic. For a large, ground-based, batch-oriented system like the RTCC, additional time spent on refinement of HAL running procedures, would be of little value compared to the same time spent on refinement of the actual compiler code.

This potential lockout problem is not peculiar to HAL. It can happen to any job on the system whose core requirements are of the same size and nature as HAL's.
2.2 Program Changes and Maintenance Procedures

During the June-September 1971 time period many changes were made to both the HAL Submonitor and the compiler itself. Most of the changes made to the Submonitor are detailed in 2.1 above. These changes were basic in nature and took a large part of the summer to research and implement properly at MSC. In addition, new compiler versions were developed at Intermetrics and were sent to Houston on magnetic tape where copies of all of the files on the tape were put on MSC-owned tapes. The required files were then transferred from tape to the HAL001 disk and the disk then dumped to a dump/restore tape as described above.

2.2.1 Updates

A three tape dump/restore system was established to maintain the integrity of the system. One tape, called the system tape, was the only one available to users. It always contained the most recent released version of the compiler. Thus, users only had to have this tape number to run HAL compilation. The two other tapes were development tapes. They were used in an alternating manner to build and checkout a new release. The alternation was necessary to provide a backup in case of some failure to make a good update. To make an update, the newest version development tape was used to restore HAL001. The update was made to the disk and then HAL001 was dumped to the alternate development tape. Even if the dump was not done, or if the update was unsuccessful, the original restore tape was still intact.

Once a version was considered ready for release, the development tape on which it resided was simply copied onto the system tape. Users specifying the system tape number as the HAL001 dump/restore automatically got the new release.

In addition to updates originating in Cambridge, some changes were made to the compiler at MSC. Small changes were communicated to Cambridge directly by long distance through the CRBE system at Harvard. In the case of larger updates, tapes were exchanged.

2.2.2 Summary of Changes Made At MSC

a) Research and implement the changes to the Submonitor to allow a more reliable core allocation.
b) Fix numerous small bugs found during checkout both in the HAL code itself and in the HAL run time library.

c) Partially implement and lay the groundwork for a more complete listing generator as detailed in the HAL Guide. This involved providing additional functions in the Submonitor to allow the HAL compiler to set a maximum number of lines per page of listing and to dynamically request the line number of the current line on the page. These new functions helped to lay the framework for the ability to control completely the layout of the HAL listing. The listing was changed to the extent that the statement and line numbers were made available and the format of the printed source code changed to increase readability.
3.0 HAL COURSES

3.1 General Description

Intermetrics personnel prepared and conducted three HAL language courses during the contract period. The material was designed for two types of audiences: 1) those seeking a broad "brush" overview of HAL, 2) those intending an indepth exposure to HAL. Two 15-hour sessions (2 1/2 days each) were given at the Manned Spacecraft Center in Houston. The first, primarily for NASA personnel and the second, for industrial contractors and other government agencies with an interest in higher order languages. For each session, the first three hours were devoted to the HAL overview; however, the overview itself was considered an integral part of the longer course.

A special third session was also conducted at the MIT Draper Laboratory, for Laboratory personnel and local industrial contractors. Because of the familiarity of these personnel with MIT's MAC language and certain similarities between HAL and MAC, an effective 1-day, 6-hour course was held. The course consisted of the overview, with elaborations and discussions, followed by a rapid presentation of the salient features of HAL.

In general, the participating students at MSC and MIT were highly motivated to learn HAL and always attempted the place HAL in perspective with respect to Shuttle applications. As a result, many provocative questions were asked and in some circumstances material discussed in class was fed back into the HAL design.

3.2 Course Preparation

The HAL courses were prepared with two objectives in mind: an overview, and a detailed study. For the overview, a balanced presentation of most of the important features and rationale incorporated into the HAL Specification Document (MSC-#01846) was designed. The purpose here was to illustrate how HAL satisfied, for the most part, the requirements imposed on a programming language for the Shuttle. Toward this end readability, vector-matrix arithmetic, data management, systems programming, real-time control and software reliability were emphasized.

The material was presented in vu-graph form and included numerous "Shuttle-like" application examples and commentary which included Intermetrics' experience with Apollo software
development. Particular attention was paid during the overview to indicate which HAL features would not be included in the first implementation for the IBM 360/75 at MSC. This was especially true for the descriptions of real-time control, controlled data sharing, and the error recovery features.

The longer HAL course was designed as an in-depth study of HAL and the overview served as an excellent orientation. This part of the course was based closely on the HAL Guide (MSC #01848) and the material was a combination of vu-graphs, references, to the Guide text and blackboard work. Only those features actually intended for implementation on the first 360/75 version were covered. (This specifically excluded real-time control, etc.)

Levels of increasing detail were presented, first with a set of vu-graphs covering all of the language features of HAL; i.e., operations, declarations, indexing, control, etc. followed by a careful tour through selected portions of the Guide. The Guide work illustrated usage, described many examples and motivated class discussions (and, in fact, contributed to subsequent corrections to the Guide). The technique of repeating subject material in levels of increasing detail; i.e. from overview to construct description to Guide with examples, proved to be an effective method of rapid assimilation and study.

In addition to text material and lecture, each student was provided with a HAL problem set as a homework exercise. Unfortunately, few found the time to actually address these problems out of class. However, during the last class session, prepared problem answers were distributed and each problem was carefully "talked-through". Actual runs on the 360/75 by the students were contemplated during the course preparation, but 360 turn-around time within the RTCC facility was not consistent with the 2 1/2 day course duration.

An outline of the HAL course material is presented in the next section and the vu-graphs for both the overview and the longer course are collected in Appendix 3.

3.3 Course Outline

3.3.1 Overview (vu-graph material)

1. Higher order language motivation and capabilities.
2. Salient features of HAL
3. Data types
4. Program organization and structure
5. HAL Statements
6. Specific Examples
7. Real-time control, including data sharing and error recovery
8. Summary

3.3.2 Longer Course (Vu-graph Material)
1. Data Operations
2. Data Declarations
3. Indexing: partitions and use of subscripts
4. Control and branching mechanisms
5. Name scope rules

3.3.3 Longer Course (Guide Material)
1. Two-dimensional input-output format
2. HAL\textsubscript{M} (HAL Mathematical Subset)
   a. Data and declarations
   b. Arithmetic expressions
   c. Assignment statements
   d. User-defined functions (SCALAR, VECTOR, MATRIX)
   e. IF Statements
   f. Illustrative problems - I
   g. Subscripts
   h. DO Statements
   i. Illustrative problems - II
   j. Subroutines; i.e., HAL PROCEDURES
k. Illustrative problems - III
l. Name scope
m. I/O Facilities
n. Illustrative problems - IV

3. Integer and Bit String Data
4. Structures
5. Bit and Character String Manipulations
6. Subscript facilities: complete
7. Implicit conversion of mixed data types
8. User-defined functions: complete
9. Array processing
10. Shaping functions: complete
11. REPLACE and DEFAULT Statements
12. "Talk-through" of problem set
4.0 NECESSARY MODIFICATIONS AND ADDITIONS

Redesign work was undertaken to increase the scope and capabilities of the HAL compiler and to promote its transferability to other computers. The first step was to redesign the variable storage philosophy and mechanization. Extensive design sessions were conducted to develop a suitable memory storage allocation system that would support the most general future goals of HAL, especially transferability (see 4.1 for more detail). This included the techniques necessary to support the calling of separately compiled HAL programs and the sharing of their data through a COMPOOL. This capability, in some form, is vital to the production of a multipass compiler.

During this time items were also dealt with that were either incomplete or had been newly defined. Thus, certain "holes" in HAL's capabilities were filled in. In addition, a number of shortcomings which had been uncovered were remedied.

4.1 Storage Allocation Problem

Certain storage allocation problems encountered during the implementation of some of the more advanced features of HAL in Phase II of the compiler (Fortran code generation) had necessitated basic conceptual changes in the allocating algorithms in the compiler.

In the original version of the algorithms, temporary storage required for partial numerical results was allocated when needed during the code generation of a HAL statement, and freed-up again not later than at the end of the statement. This caused two major difficulties. Firstly, when temporary storage was required to hold the value of an argument in a procedure or user function invocation, special "unfreeable" temporary storage had to be used to prevent it from possibly being reallocated in the body of the procedure or user function. Secondly, in HAL statements containing user function invocations, (possibly nested), temporary storage allocated for partial results before the invocation code was generated had also to be masked "unfreeable" for the same reason. Other more subtle considerations finally made a complete restructuring of the algorithm essential.

The idea of providing completely dynamic storage allocation of execution time was rejected as requiring too many basic changes in the mode of operation of Phase II of the compiler. Instead a static scheme similar in some respects to the original...
was adopted. In this scheme temporary storage for the program, and for each procedure or user function are allocated within mutually non-overlapping segments. A program or subprogram may have one segment or several non-contiguous segments of varying sizes dedicated for its use, depending on its requirements. The sum total of all segments constitutes a single continuous area of storage (except possibly for word boundary alignments). At the microscopic level within the bounds of a segment, storage is allocated and freed exactly as it was in the original allocation scheme.

Under this scheme, no temporary storage need be marked "unfreeable" no matter to what use it is put. Furthermore, the scheme has resulted in considerable simplification and unification of other storage allocation mechanisms in operations at code generation time.

4.2 Miscellaneous Improvements

1. Arraynesses:

* reorganization of the mechanism controlling the utilization of statement arraynesses, especially with regard to utilization by arrayed subscripts of arrayed variables, and by the arguments of user functions.

* implementation of the arrayed subscripted variable as an input or assign argument in a function or procedure call.

2. Cosmetics and Statistics:

* generation of Phase II timing information, improvement of error message format, generation of statistics on certain critical parameters of Phase II operations.

* introduction of toggle directives to control Phase II and subsequent Fortran IV operation.

3. Shaping Functions:

* introduction of a limited range of shaping and conversion functions: INTEGER, SCALAR, MATRIX, and VECTOR (no arrayed arguments or results).

4. Program Calling:

* setting-up operating mechanisms for calling independent (i.e. separately compiled) HAL programs to "any" nest level, non-recursive
creation of mechanisms for saving HAL programs in an object library.

5. I/O Routines

- first, implementation of full-scale HAL READ/WRITE statements fixed, uni-channel input and output, fixed record length (printer and punch only).

6. Bit Strings:

- fundamental bit string operators were implemented. Included were terminal and array subscripting and the AND, OR, and NOT operations. Bit strings are limited to not more than 32 bits; they have been implemented in full-word, half-word, and byte form.
5.0 HAL TRANSFERABILITY

5.1 Technical Approach

5.1.1 Background

The quest for easy transfer of operational programs from one computer to another has occupied the minds of many men since the early days of computer technology. The importance of this capability has grown considerably as the computer explosion has populated our society with countless kinds and types of computers with ever decreasing and more attractive price tags, and yet soaring software costs through higher programmer salaries has made conversion more difficult due to the huge investment in operational software for existing computers. The solutions to the programming transferability problems can be categorized into one of the following types:

1. Hardware emulators - In order to maintain compatibility many modern computers have included hardware or microprogram features that permit them to simulate other (usually older) computers. Thus, existing programs can still be executed.

2. Software translators - A program is developed that will take programs that were written for machine X and translate them into equivalent programs for machine Y. This approach has been limited since the technique is seldom 100% successful, even when the two computers are almost identical.

3. Higher level languages - If programming is confined to high level languages, hopefully machine independent, and a translator or compiler is used to produce the actual machine code, then it should theoretically be possible to feed the same higher level source statements into a translator to another brand of computer and produce a program that performs functionally equivalent tasks. The difficulty here is whether the language and the interpretations given it by compiler writers are truly machine independent.

5.1.2 Level of Transfer

In the design of the HAL compiler system for the 360 implementation, Fortran was adopted as the output language from the code generator. A principal reason expressed for the
somewhat unusual procedure was to promote machine transferability. Fortran IV is the most widely used programming language and ANSI Fortran IV purports to be defined in a machine independent way. Production of the HAL code generator was initiated with the avowed intent of producing ANSI standard Fortran IV. If this could have been rigidly adhered to, transferability would have been automatically produced at the lowest level. The output of Pass 2 would be suitable for submission to any Fortran compiler. As it is, there exists some 360 specific Fortran output and some assembly language subroutines, but the job required to take the Fortran output of the HAL compiler and move to another computer is a minor one. Figure 5.1 depicts the steps in the HAL compilation process. The Fortran output of Pass 2 may be physically moved (in card or tape form) to another computer facility.

Contrast this transferability with the proposed system for construction of a HAL code generator for a flight computer. (See Figure 5.2) In this case, a new Pass 2 is required, the same output of Pass 1 (HALMAT) is used. This is the traditional approach. Every time that HAL is desired for a different target computer, another version of Pass 2 is required. This is a mid-level transfer.

However, neither of the above approaches will satisfy the needs of another general purpose computer facility. The reason is that they are only partial transfers. Although they produce code for another computer, the compiler itself still must run on the initial computer, the IBM 360 in this case. This is poor operationally. It means that a user must submit his HAL source program to the 360 for compilation and then take the object program to the other computer for execution. (This approach is perfectly adequate for a flight computer where the usual mode of operation is via simulation on his general purpose computer. Besides, the flight computer is usually of such limited size that compilation on it is not possible even if one were physically available.)

A total transfer is needed for implementation on another large commercial computer. It requires that the entire system be transferred, "lock, stock and barrel". Then the user can compile and execute on the new facility with no further need of the 360. This is a more demanding requirement since it necessitates moving the entire compiler to a different computer complex. The result is a high level transfer or complete conversion.

5.1.3 Method of Attack

There are three avenues of approach that might be followed to achieve a compiler transfer. They are:
Fig. 5.1 Construction of the HAL Compiler System
Fig. 5.2 Proposed Construction of HAL Compiler for Flight Computers
1. Reprogram the HAL compiler for Brand X: This technique looks at the process as a one-of-a-kind step and selects whatever seems most appropriate for machine X, be it assembly language or whatever. Then the job is done. This is the brute force approach and has no generality whatsoever.

2. Reprogram the XPL compiler for Brand X: HAL is written in XPL, a simplified subset of PL/1. Thus, it would be relatively easy to transfer to another computer that supports PL/1; however, there are few that do. But we could transfer XPL to another computer. Since XPL is itself written in XPL, the transfer could be accomplished by a mid-level transfer. (A new code generator on the 360 that produced code for Brand X would allow a version of XPL to be compiled that would execute on Brand X.) However, this approach also lacks generality; each new computer requires another code generator, itself not an easy task.

3. Reprogram HAL into a language more widely supported: If HAL could be rewritten in a language that was universally supported, then transfer problems would be minimized. The most widely used language is Fortran. And since Fortran is now produced by HAL, an interesting variation of this technique is immediately suggested. If HAL was rewritten in HAL and compiled on the current HAL compiler then the result would be Fortran source cards that would be suitable for compilation on any computer with a Fortran compiler. Thus, the transfer of HAL to almost any large scale computer could be achieved by minor changes to the Fortran output (chiefly in the area of data types and declarations) and the recoding of machine-dependent library routines. But the latter must be done anyway if HAL is to execute on Brand X; even the low-level transfer needed it. The extra task is the effort needed to rewrite HAL in HAL. But having done it once, it would not need to be done again to affect other transfers. The generality of this approach resolved the issue in its favor.

5.2 Translation of XPL Programs Into HAL

5.2.1 Introduction

This is a brief discussion of the methods used when translating a program from XPL into HAL. It is intended to provide a useful guide to a process which requires a considerable amount of analysis and judgement on the part of the individuals performing the work. This end is achieved by presenting the
essentials of language differences and by discussing examples of coding economies possible through the use of HAL. Explicit illustrations demonstrate the translation of several XPL constructs into HAL.

Translation of some form was necessary since it was intended that a copy of the HAL compiler be implemented on the Univac 1108. There were two general strategies available to Intermetrics as alternate means to affect this implementation. As one possibility, we could have rewritten or modified the XPL system to implement it on the 1108, then we would have been able to recompile the original XPL source code of HAL on the 1108. This approach lacks generality and involves the difficulties of emitting executable and efficient low level code for a machine with extant high level software. As a second alternative, we could rewrite the HAL compiler in a source language which maps via an existing processor onto a target language recognized by existing 1108 software.

This latter course was chosen, using HAL itself as the source language, and using the HAL/360 compiler as the mapping onto Fortran IV, a target language understood by the 1108 (as well as other large scale computers). This course provided a large amount of generality, and also proved to be easiest to carry out because of HAL's many high level features and the convenient degree of similarity between HAL and XPL.

The two-dimensional input scanner employed in Pass 1 of the HAL compiler was chosen as an initial goal. If a program as complex as this worked satisfactorily once debugged, we could be fairly certain that no part of the compiler would create a problem. The translation strategies and methods described in this document were devised in the process of successfully rewriting the input scanner. As an added bonus of this choice of translation strategy, the use of HAL as a source language proved to be exceptionally helpful in the process of debugging the current HAL/360 compiler. Quite a number of bugs which were invisible prior to this large scale application were exposed and repaired in the process.

5.2.2 Methodology

5.2.2.1 Variables. Variable declarations differ somewhat between XPL and HAL. Each individual DECLARE statement must be examined for possible changes.

BIT variables are declared identically in both XPL and HAL. The length specification is also identical in the two languages.
Ex. DECLARE X BIT(8);

FIXED variables in XPL are functionally identical to INTEGER variables in HAL. Therefore, mere substitution of the word INTEGER for FIXED is all that is necessary to make the language change. The REPLACE facility in HAL is the simplest method of substitution. Note here that any XPL variable names which correspond to HAL reserved words must be changed or augmented; i.e., the XPL identifier VECTOR could become VECTOR1 in HAL. Note also that the break characters @, #, and $ are not legal identifier break characters in HAL and XPL identifiers using them must be replaced by legal HAL identifiers.

CHARACTER variables have somewhat different properties in XPL and HAL. In XPL, character variables are implicitly varying with a maximum length of 256 characters. However, VARYING character strings in HAL are currently limited to a length of 255. Thus, the general substitution rule for character declares is to change:

\[ \text{DECLARE ALPHA CHARACTER; (XPL)} \]

...to

\[ \text{DECLARE ALPHA CHARACTER (255) VARYING; (HAL)} \]

In cases where a string is known to have a maximum length considerably less than 255 characters, it may be declared as such. Also, if a string is to be of fixed length (as with an initial unchanging value), the VARYING attribute should also be omitted.

Factored declarations in XPL and HAL are also implemented differently and involve a complete rewriting of the statements. For example:

\[ \text{DECLARE (I,J,K) FIXED, L BIT(8); (XPL)} \]

becomes:

\[ \text{DECLARE INTEGER, I, J, K; (HAL)} \]
\[ \text{DECLARE L BIT(8);} \]

A word of caution is necessary at this point. XPL initializes all FIXED and BIT variables to "0" and all character strings to null strings unless otherwise specified by the INITIAL modifier. Any variable not explicitly initialized in HAL will have unpredictable contents. When in doubt as to whether the program itself initializes variables, include an INITIAL(0) specification
on the DECLARE statement (INITIAL('') for character strings).

The LITERALLY attribute in XPL is used to perform macro substitution for identifiers. The REPLACE statement in HAL performs the same function. The statement:

\[
\text{DECLARE FOREVER LITERALLY 'WHILE "1"'; \hfill (XPL)}
\]

becomes

\[
\text{REPLACE FOREVER BY 'WHILE TRUE'; \hfill (HAL)}
\]

5.2.2.2 Arrays. When transferring array declarations and specifications from XPL to HAL there are a number of ground rules to follow. First, XPL subscripts start at 0 and the dimension specified is the highest allowable subscript. Therefore, an XPL array declared with an arrayness of 99 actually consists of 100 elements and must be declared as such in HAL, since all HAL subscripts start at 1 for an array. Thus,

\[
\text{DECLARE ABLE(99) FIXED; \hfill (XPL)}
\]

becomes

\[
\text{DECLARE ABLE ARRAY(100) INTEGER; \hfill (HAL)}
\]

The word ARRAY must be supplied in HAL in array declarations.

Frequently in XPL the name of an array appears without a subscript. This means an implied reference to the 0th element of the array. However, in HAL, an array name without an explicit subscript implies reference to the entire array, not the first element. Therefore, for conversion, all such occurrences of non-subscripted array names must be translated with the explicit subscript of 1. Thus, the following XPL segment:

\[
\text{DECLARE ARR (9) FIXED, B CHARACTER;}
\]

\[
\text{B = ARR; \hfill (XPL)}
\]

becomes in HAL:

\[
\text{DECLARE ARR ARRAY (9) INTEGER,}
\]

\[
\text{B CHARACTER (255) VARYING;}
\]

\[
\text{B = ARR_1;} \hfill (HAL)
\]
In general, unless the 0th element of an XPL array is known not to be used, indexing expressions must be augmented by adding one to the original subscript expression, and not by changing the computation of indices in other statements. This is especially true when array references are made using Boolean values of 0 and 1 as switches for referring to one of two array elements. Thus, the XPL sequence:

\[ IX = IY + IZ; \]
\[ VALUE = \text{ABLE}(IX); \]

should become in HAL:

\[ IX = IY + IZ; \]
\[ VALUE = \text{ABLE}_{IX} + 1; \]

as opposed to the HAL sequence:

\[ IX = IY + IZ + 1; \]
\[ VALUE = \text{ABLE}_{IX}; \]

as the latter form could possibly change the operational characteristics of the program.

Finally, XPL allows the specification of a subscript on a variable which is not declared as an array. This allows certain machine dependent coding "tricks" to be performed. Consider the following XPL sequence:

\[
\text{DECLARE INDEX FIXED, INDEXTAB (199) BIT (8);} \\
\text{DO I = 1 TO 50;} \\
\text{INDEX (I) = 0;} \\
\text{END;} \\
\]

This program in effect zero's out INDEXTAB with 50 references, rather than the 200 required to clear the individual INDEXTAB elements. This sequence is illegal in HAL and may be coded as follows in HAL:

\[ \text{INDEXTAB} = 0; \]

where the non-subscripted version of the name implies setting the array to zero.
An extra step is involved when translating statements utilizing arrays of character strings or bit strings. A colon (:) must follow the array element subscript, to distinguish it from the individual character or bit subscript which is the default in HAL for these types of variables. It may be used following any array subscript, but is required in the above named instances to prevent ambiguity.

Ex:

DECLARE A CHARACTER(5),
    B ARRAY(10) CHARACTER(10);

B1 TO 5 = A;

B1 TO 5: = A;

In the first statement, characters 1 to 5 of all ten array elements of B are set to the value of the characters in A; in the second statement, the first five array elements of B are set to the value of A (padded with blanks to make the total length ten).

5.2.2.3 Built-in Functions. The XPL functions ADDR and INLINE are not available in HAL, and because of the machine independence of the language no corresponding functions exist. In the HAL compiler, fortunately, most such functions are used to manipulate data types not existing in XPL but which do exist in HAL.

The SUBSTR and BYTE functions in XPL are replaced with character string subscript notation in HAL. Examples of both forms of BYTE and SUBSTR substitution follow:

a. BYTE (CHAR_STRING) (XPL)
   becomes
   CHAR_STRING1 (HAL)

b. BYTE (CHAR_STRING, N) (XPL)
   becomes
   CHAR_STRINGN+1 (HAL)

c. SUBSTR (CHAR_STRING, START) (XPL)
   becomes
   CHAR_STRINGSTART+1 TO # (HAL)
d. SUBSTR (CHAR_STRING, START, N)  
becomes  
CHAR_STRINGN AT START+1

The functions SHL and SHR are used for doing word manipulation in XPL. For positive arguments, the SHL function may be replaced by multiplication by the appropriate power of two. The SHR function is more complex as integer division is not allowed in HAL. Since SHR is normally used to isolate a field of a packed word, the BIT shaping function can be used to achieve the same results.

For example, the XPL sequence:

DECLARE (ENTRY, PART) BIT (16),
    WORD FIXED;
PART = SHR (ENTRY, 4);
PART = SHR (WORD, 16);

becomes in HAL:

DECLARE BIT (16), ENTRY, PART;
DECLARE WORD INTEGER;
    PART = ENTRY 1 TO 12;
    PART = BIT 1 TO 16 (WORD);

In XPL, it is legal to assign the result of a relational expression to a BIT type variable. This is illegal in HAL. Thus, the statement

TEST = A > B;  

must become:

IF A > B THEN TEST = TRUE; ELSE TEST = FALSE;  

5.2.2.4 Constants. The following constant conversion rules apply:
"ABDF" or "(4)ABDF" becomes HEX'ABDF'
"(1)11010" becomes BIN'11010'
"(3)70346" becomes OCT'70346'

The quartal constant "(2)20312" must be converted to either BIN'1000110110' or HEX'236'.

The use of the BYTE function, notably BYTE('C'), to allow use of the internal representation of the character as a numeric quantity is accomplished in HAL by stating BIT('C'), or INTEGER (BIT('C')) where implicit Bit-to-Integer conversion may not take place.

5.2.2.5 Procedures. In XPL, all subroutines and functions are declared as PROCEDURE's. The RETURN statement may or may not pass back a value. If an XPL PROCEDURE which returns a value is called by the CALL statement, the returned value is ignored. In HAL, there are two classes of routines: PROCEDURE's and FUNCTION's. A PROCEDURE does not allow a value to be returned in the RETURN statement, whereas a FUNCTION demands that a value be returned. Thus, XPL PROCEDURE's that return values must be declared as FUNCTION's in HAL. Any such FUNCTIONS invoked by the CALL statement in XPL must be changed to the form:

\[
\text{DUMMY VARIABLE} = \text{FUNCTION NAME}(X);
\]

where the dummy variable is some unused name in the HAL program with the mode of the called function.

Also, in XPL, all formal parameters are call-by-value parameters. This presents a problem in HAL because, 1) PROCEDURE and FUNCTION parameters may not be assigned values within HAL programs, unlike XPL which freely allows such assignments, 2) the alternative in HAL, the ASSIGN list, is treated as a list of call-by-reference parameters, where assignments to such parameters are passed back to the calling program, whereas in XPL, parameter assignments do not reflect back to the calling program. Therefore, in all FUNCTIONS and PROCEDURES where assignments to formal parameters are made, a procedure prologue must be coded to assign the formal parameter (with an augmented name) to a local variable with the same declared properties with the original parameter name. Thus, the following XPL program segment:
ALPHA: PROCEDURE (BETA, GAMMA);

DECLARE BETA FIXED, GAMMA CHARACTER;

. BETA = BETA + 1;

. END ALPHA;

becomes in HAL:

ALPHA: PROCEDURE (BETA_PRIME, GAMMA);

DECLARE INTEGER, BETA, BETA_PRIME;

DECLARE GAMMA CHARACTER (255) VARYING;

BETA = BETA_PRIME;

. BETA = BETA + 1;

. CLOSE ALPHA;

when BETA is used as an assigned variable in the procedure, whereas GAMMA is not. The HAL compiler itself can be used to detect such occurrences, since assignments to parameters will be flagged as errors, significantly reducing the amount of program scanning necessary.

Note: Notice that the word CLOSE was used on the last line of the sample rather than the standard END. When closing a function or procedure in HAL, the word CLOSE is substituted for END. END is only used to signify the end of the DO loop or a DO case.

5.2.2.6 DO Statements. The DO case statement in HAL is similar to that in XPL, the only difference being that the first group of statements are executed when the DO case argument is equal to 0 in XPL and the first group of statements in HAL are executed when this argument is equal to 1. The following XPL sequence:
DO CASE I;
DO; /*CASE0*/
... 
END; /*CASE0*/
... 
END; /*OF DO CASE*/

translates to the following HAL sequence:
DO CASE I + 1;
DO; /*CASE1*/
... 
END; /*OF CASE 1*/
... 
END; /*OF DO CASE*/

When translating a DO case group from XPL to HAL, 1 must be added to the argument of the DO case statement rather than to change the value of the variable itself. DO case statements are translated in this manner to preclude the possibility of causing errors elsewhere in the compiler. It is not really possible to be certain that the change of the variable's value might not cause problems elsewhere. The looping statement:

DO IX = 1 to 10; (XPL)

simply becomes:

DO FOR IX = 1 to 10; (HAL)

The word FOR is required to distinguish this type of DO statement from the DO CASE or DO WHILE statements.

5.2.2.7 INPUT/OUTPUT. The primary input/output statements in XPL are the INPUT and OUTPUT pseudo-variables. To read a card image, the following statement is used:

CARD_IMAGE = INPUT;

Similarly, to write a line the following statement is used:

OUTPUT = NEXT_OUTPUT_LINE;

Both pseudo-variables are character string type and imply a new input/output record on each occurrence.
The corresponding HAL statements to read the same card image and print the same line are as follows:

```
READALL(5) CARD_IMAGE;
WRITE(6) NEXT_OUTPUT_LINE;
```

Note that READALL, not READ, is used for input, as this forces reading an entire card image. READ into a character variable stops at any legal input delimiter.

5.2.2.8 Format of HAL File. The format of the input file is for the most part free of conventions. The only exception to this is that Column 1 may only be used to contain special letters. The following letters may appear in Column 1: C, D, E, M, and S.

These letters specify what type of line is contained on that current image. The letter C is to specify that the following text is to be treated as a comment and not actually compiled. D is used only for special compiler directives such as an INCLUDE file specified on this line. The letter E constitutes an exponent line which is part of the multi-line input format which HAL offers. M specifies that the following is the main line of the multi-line input, and S specifies a subscript line again which is part of the multi-line input. When using the single line format of HAL input, the M may be omitted from the line as long as text begins in Column 2 or after. The letter M is assumed on all lines which do not contain a character in Column 1. The above exception is the only one which pertains to the format of a HAL program.

Long and complicated HAL statements may be continued over as many cards as necessary just as in XPL. Certain equations which are broken up into several steps in the XPL version may be condensed into one large equation in HAL, resulting in a savings of temporary variables. (This is because XPL limits the number of expression temporaries in a statement to three registers. HAL has no such restriction.)

5.2.3 Debugging

The debugging procedure can be made quite simple by the use of various options which may be specified when compiling a HAL program. One may specify toggles on comment lines in HAL, which produce an identifier trace, a listing of the HALMAT code produced, and a list of the Fortran produced from Phase 2.
When errors occur, it is easy to trace the problem by consulting the three listings as mentioned above. Also, a check of the cross-reference listing produced greatly speeds debugging time since it is possible to determine in which statement a variable is either referenced, declared, or set. When a new section of code is added, a toggle can be set in a comment line at the beginning of the HAL program, which disables the call to Phase 2 of the HAL compiler. This is done to save computer time, since Phase 1 could perform a syntax check. When all syntax errors are eliminated, Phase 2 could then be called and Fortran output could be produced and subsequently compiled by the Fortran compiler.

It is, of course, much easier to debug a higher level language program than to debug assembly code, since ideas are clearly specified by the code being read, whereas in assembly language the intent is not always quite clear. In fact, when translating the in-line code it was sometimes necessary to speak to the person who had originally coded that section before a clear understanding could be gotten in order that the translation could be performed.

5.2.4 Conclusions

At the time of this writing, some HAL features are still unimplemented. Because of this, certain sections of the translated code have as of now not been tried or debugged. However, that code which has been debugged and executed seems to prove that HAL is a language with which a large compiler can be easily written and debugged. The fact that HAL implements floating point arithmetic also eliminated a great deal of the complicated code necessary in the original XPL version. This fact alone made readability of the final copy much easier than the complicated in-line code which appears in the corresponding sections of the original copy.
5.3 Feasibility Demonstration ("HAL-in-HAL")

5.3.1 Objective

The HAL-in-HAL program was written as an experiment to prove whether or not the HAL language was suitable for writing translator systems, as well as aerospace applications. The program consists of a rewrite of the two-dimensional read routines originally coded in XPL for the HAL/360 compiler, utilizing the conversion techniques outlined in Section 5.2 above. These routines represent a full test of the character and bit manipulation facilities normally required for translator and system coding.

5.3.2 Test Program Description

The test program consists of an elementary scanning routine which utilizes the STREAM procedure for receiving its character-by-character input. STREAM converts the two-dimensional HAL input cards into the corresponding one-line format which is required by the scanner and subsequently the lexical analyzer. The test scanner repeatedly calls STREAM building-up identifier and numeric strings as tokens, as well as treating any special character as an automatic token. These are printed out as they are encountered. The test scanner is concurrently building-up an output line image which is a reflection of the input character received from STREAM. Whenever a semi-colon (;) is encountered, the current statement line, along with its corresponding over-punch markers, is printed, showing what the one-line format of the HAL statements looks like. A question mark (?) is used to indicate the end of the input stream for the purposes of this test. See Figure 5.3 for a flow chart of the test scanner. (Program listing - Statements 544-582 in Appendix B.)

5.3.3 Results

The HAL-in-HAL experiment has proved conclusively that HAL can be used successfully as a compiler implementation tool. Although HAL has no machine dependent features, (which frequently are designed into implementation languages), this experiment has proved that such features are not a requirement for compiler implementation, but rather merely a convenience item to circumvent known code generation inadequacies in the compiler. The HAL implementation is concise, readily followed, and understandable (even more so than the XPL version of the same program).
Initialize write 'BEGIN'

Call Stream

No

Yes

next_char = ' '?

Blank_flag = false

Yes

Blank_flag = true

No

Blank_flag

Concatenate next_char to Built

No

over_punch

Yes

Add blank to Built_up

Add over_punch to Built_up

Figure 5.3
Figure 5.3 (Cont.)

Yes
next_char letter or no?

No

Concatenate next_char to Built_token

Yes

over_punch?

No

Built_o_p = over_punch

Yes

next_char = Blank

No

Write 'Blanks =''Blank_count

Write 'Token =''next_char

next_char = '',''

Write Built, Built_up; Set to Null

A2

Length Built_token =? 0

Yes

Write Built_token; Built_o_p; Set to null

No
next char = '??'

Call Print_Summary

Write 'END OF TEST'

END
The checking facilities of the HAL compiler can detect numerous logical errors without having to impose the strict definition rules of XPL. Uninitialized variables are easily detected, as are parameter mis-matches. The bulk of the debugging time for HAL-in-HAL was in streamlining the program to make the HAL version more readable, as well as more efficient, since the rule of adding one to all XPL subscripts as a general rule turned out to be both awkward and confusing in many instances. The final version of STREAM is much more efficient than the original translation performed utilizing the rules of Section 5.2. Programs originally coded in HAL will obviously not experience this problem.
APPENDIX A.

HAL Course Material
A.1 OVERVIEW
PREFACE

* HAL developed by Intermetrics, Inc.
  * Language design
  * Compiler design and implementation

* Significant Objectives
  * Increased readability
  * Increased reliability
  * Real time control

* Capabilities
  * Primarily designed for on-board computer
  * General enough for:
    * ground support and verification
    * other real-time applications
SHUTTLE LANGUAGE REQUIREMENTS

* Software Applications
  * Navigation, guidance, targeting
  * Vehicle control
  * Operating systems
  * Data management
  * Communications and displays
  * Support software
  * On-board checkout and monitor

* Computer Environment
  * Wide range of computers (Flight and Ground)
  * Fixed- and floating-point
  * Simplex, multi-computer, multi-processor

* Language Characteristics
  * Clarity and readability
  * Enforcement of standards and conventions
  * Extensive automatic checking (compile- and run-time)
  * Facilitate software management
  * Promote modularization

INTERMETRICS
Some Observations
1. The writing of code is closely tied to the specifications.
2. The time required for computer preparation is small compared to the program life.
3. A lengthy period of debug and modification must be provided.
4. Period of program usage extends many times that of program generation.
5. Many more people will use a program than generated it.

Conclusion
The computer language should promote understanding of the software. The listing should tend toward self-documentation.

INTERMETRICS
### SALIENT FEATURES OF HAL

<table>
<thead>
<tr>
<th>Capability</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Two-dimensional Input-Output Annotation of variables</td>
<td>* Increased readability</td>
</tr>
<tr>
<td>2. Complete vector-matrix arithmetic</td>
<td>* Targeting, guidance and control</td>
</tr>
<tr>
<td>3. Data array and structure handling</td>
<td>* Data management</td>
</tr>
<tr>
<td>4. Bit and character manipulations</td>
<td>* Systems, communications and I/O</td>
</tr>
<tr>
<td>5. Real-time control statements</td>
<td>* Command and control</td>
</tr>
<tr>
<td>6. Data-Pool (COMPOOL), controlled sharing and name scope</td>
<td>* Increased reliability</td>
</tr>
</tbody>
</table>

**SLIDE 4**
ADVANCED FEATURES

- TWO-DIMENSIONAL (MULTI-LINE) INPUT AND OUTPUT
- VECTOR AND MATRIX DATA TYPES AND OPERATORS
- TASK SCHEDULING AND SYNCHRONIZATION STATEMENTS FOR REAL-TIME CONTROL
- CONTROLLED SHARING OF DATA AMONG MULTIPLE USERS THROUGH A COMPOOL AND DATA LOCKING STATEMENTS
- STATEMENTS TO MANIPULATE DATA-GROUPS (ARRAYS AND STRUCTURES) AND POWERFUL METHODS TO PARTITION AND INDEX THEM
- OUTPUT ORIENTED. LANGUAGE IS SLANTED TOWARDS PRODUCTION OF UNDERSTANDABLE AND UNAMBIGUOUS OUTPUT LISTING RATHER THAN MINIMIZING KEYSTROKES ON INPUT

A SIMPLE SCIENTIFIC SUBSET IS DEFINED AT THE OUTSET THAT WILL PERMIT EASY USE BY THOSE WITH A SCIENTIFIC BACKGROUND
HAL Data Types and Organizations

Types

- Arithmetic
  - Scalar
  - Integer
  - Vector
  - Matrix

- String
  - Bit
  - Character

Organizations

- Array
  - Individual Data-Type

- Structure
  - Array

Combinations of Data-Types

Unique notation: VECTOR:NAME, BIT STRING:NAME, CHARACTER STRING:NAME, MATRIX:NAME, ARRAY:[NAME], STRUCTURE:{NAME}
EXAMPLES OF DATA TYPES

SCALAR: -126.04

INTEGER: 126

VECTOR: 5, -26.4, 3.061

MATRIX: 5, -26.4, 3.061,
       1, -67.2, 106.1,
       0, 73.29, 0.06

BIT STRING: 10110101

CHARACTER STRING: VOLTAGE ON BATTERY B 2 VOLTS BELOW SPEC
STRUCTURE ORGANIZATION OF DATA

DECLARE 1 NAV_STATE (2);
  2 STATE (2),
    3 TIME PRECISION (8),
    3 R VECTOR PRECISION (10),
    3 V VECTOR PRECISION (10),
  2 STATE_FLAGS,
    3 BODY_FLAG BIT INITIAL (TRUE),
    3 PHASE_FLAG BIT,
  2 W MATRIX (9, 9) PRECISION (10);
HAL PROGRAM ORGANIZATION

Data Compool

Symbolic Library

Program #1

Program #2

Program #N
SCOPE OF NAMES

- Scope is the region in which a name is recognized.
- Scopes are defined from the outermost block toward the inner; i.e.,
  
  \[
  \text{Compool} \rightarrow \text{Program} \rightarrow \text{Procedure} \rightarrow \text{Function} \rightarrow \text{Procedure} \rightarrow \text{Function} \rightarrow \text{etc.}
  \]

- Names defined in an inner block are never recognized in an outer block. Inner blocks effectively isolate locally defined variables.
ABLE: PROGRAM;
DECLARE VECTOR (5) A,B,C;
\[ \bar{A} = \bar{B} + \bar{C}; \]

BAKER: TASK;
DECLARE A INTEGER;
PROCEDURE;
DECLARE X;
DECLARE A BIT (10);
END CHARLIE;
END BAKER;

GRAB: PROCEDURE;
DECLARE X VECTOR (4);
END GRAB;

END ABLE;

A,B,C are vectors (5)
A is now an integer
B,C are vectors (5)
A is now a bit string
X is a scalar
A,B,C are vectors (5)
X is a vector (4)
HAL Statements

1. **Assignment**
   
   LABEL: VARIABLE = EXPRESSION;

2. **Declare**
   
   DECLARE -------

3. **Control**
   
   GO TO ----, IF-statements, DO-statements,

4. **Block**
   
   Procedures, Functions, Tasks, Updates, Programs

5. **Real-time Control**
   
   Schedules, Waits, Signals, Locks
EXAMPLES OF ARITHMETIC OPERATIONS
(From Apollo Navigation Equations)

\[ \bar{Z} = \bar{W}^T \bar{E}; \]

\[ \Omega = \bar{Z} \bar{W}^T / (\text{ZMAG}^2 + \text{ALPHA}^2); \]

\[ \Delta \bar{X} = \Omega \Delta \bar{Q}; \]

\[ \bar{X} = \bar{X} + \Delta \bar{X}; \]

\[ F = 1 + (\text{ALPHA}^2 / (\text{ZMAG}^2 + \text{ALPHA}^2))^{1/2}; \]

\[ \bar{W} = \bar{W} - \Omega \bar{Z} / F; \]

\[ \bar{Z} = \bar{W}^T \bar{b}; \]

\[ \omega^T = \frac{1}{\bar{Z}^2 + \bar{a}^2} \bar{Z}^T \bar{W}^T \]

\[ \delta \bar{X} = \omega \delta \bar{Q}; \]

\[ \bar{X} = \bar{X}' + \delta \bar{X}; \]

\[ \bar{W} = \bar{W}' - \frac{\omega \bar{Z}^T}{1 + \sqrt{\bar{a}^2 / \bar{Z}^2 + \bar{a}^2}} \]

where \( \bar{b} \) is the geometry vector,
\( \bar{W} \) is the square root of the covariance,
\( \bar{a}^2 \) is the measurement variance,
\( \bar{X} \) is the state vector.
CONTROL, LOGIC AND COMPUTATION  
(Cross product steering of Apollo vehicle)  

Involves scalars, 3-d vectors, 3x3 matrices, "Booleans"

\[
\text{XSTEER: IF TGO < 4 THEN DO;}
\]

\[
\begin{align*}
\bar{\Omega}_\text{MEGA}_\text{CNB} &= 0; \\
\bar{\Omega}_\text{W} &= \text{OFF}; \\
\text{SCHEDULE ENGINE_OFF AT (TIME+TGO)} \\
\text{PRIORITY (20) E_OFF_ID;} \\
\text{GO TO START;} \\
\text{END;}
\end{align*}
\]

\[
\bar{\Delta}_\text{ELM} = C \bar{\Delta} \text{ELT} - \bar{\Delta}_\text{ELV};
\]

\[
\bar{\Omega}_\text{MEGA}_\text{C} = K(\bar{V}_\text{G}*\bar{\Delta}_\text{ELM})/(\text{ABVAL (V}_\text{G}) \text{ ABVAL (}\bar{\Delta}_\text{ELM})
\]

\[
\bar{\Omega}_\text{MEGA}_\text{CNB} = \hat{\text{SMNB}} \hat{\text{REFSMAT}} \bar{\Omega}_\text{MEGA}_\text{C};
\]

\[
\text{GO TO START;}
\]

where TGO \equiv "time-to-go"

\[
\bar{V}_\text{G} \equiv "velocity-to-be-gained"
\]

\[
\bar{\Omega}_\text{MEGA}_\_ \equiv \text{rate command}
\]
EXAMPLES OF MATRIX PARTITIONING

Given: 9x9 covariance matrix \( E \) of errors in position, velocity and landmark location. That is,

\[
\begin{bmatrix}
E_{p-p} & E_{p-v} & E_{p-l} \\
E_{v-p} & E_{v-v} & E_{v-l} \\
E_{l-p} & E_{l-v} & E_{l-l}
\end{bmatrix}
\]

1. RMS Errors

\[
\text{RMS}_\text{POS} = \sqrt{\text{TRACE}(E_{1 \rightarrow 3, 1 \rightarrow 3})};
\]

\[
\text{RMS}_\text{VEL} = \sqrt{\text{TRACE}(E_{4 \rightarrow 6, 4 \rightarrow 6})};
\]

2. Initialize \( E \) for new landmark

\[
E_{1 \rightarrow 6, 7 \rightarrow 9} = 0;
\]

\[
E_{7 \rightarrow 9, 1 \rightarrow 6} = 0;
\]

\[
E_{7 \rightarrow 9, 7 \rightarrow 9} = \text{MATRIX}_{3,3}(A^2, 0, 0, 0, B^2, 0, 0, 0, C^2);
\]
BIT AND CHARACTER MANIPULATIONS

Suppose the system-status word is made up as follows:

```
SYSTEM_STATUS 1 0 1 1 1 0
```

```
system status
```

Example:

A = 'SYSTEM STATUS:';

DECODE:

```
DO CASE SYSTEM_STATUS 1 TO 3;
  MESSAGE = ENGINE | A;  CASE 1
  MESSAGE = POWER | A;  CASE 2
  MESSAGE = IMU | A;  CASE 3
  MESSAGE = LIFE_SUPPORT | A;  CASE 4
  *
  *
END;
```

```
DO CASE SYSTEM_STATUS 4 TO 6;
  MESSAGE = MESSAGE | 'O.K.';  CASE 1
  MESSAGE = MESSAGE | 'RECONFIGURED';  CASE 2
  MESSAGE = MESSAGE | 'IN SELF-CHECK';  CASE 3
  *
  *
END;
```

END DECODE: WRITE (DISPLAY) MESSAGE;

SLIDE 12
EXAMPLE OF IF-STATEMENTS
(Flag-checking in Apollo Rendezvous Data Processing)

A:  WAIT FOR SYNCH_SIGNAL;

     IF REFSMMAT_FLAG THEN
          IF R_60_OP THEN GO TO A;
          ELSE IF UPDATE_FLAG THEN DO;
              IF VHF_RANGE THEN
                  IF TIME>60-TIME_VHF THEN GO TO VHFREAD;
              GO TO D;
          END;
          ELSE IF TRACKFLAG THEN GO TO D;
     GO TO EXIT;

Note:  ELSE always refers to immediately preceding IF (except when IF
       is within a DO group)
EXAMPLE OF A PROCEDURE
(The Apollo Time-Radius Routine from GSOP)

CALLER:

CALL TIME_RADIUS (\bar{RT}2, \bar{VT}2, (ABVAL (\bar{RT}2) - 30480), MU_EARTH, 
\hat{T}_R\_FLAG)); ASSIGN (TIME_32, \bar{RT}3, \bar{VT}3);

SUBROUTINE:

TIME_RADIUS: PROCEDURE (\bar{A}, \bar{E}, C, D, E) ASSIGN (F, \bar{G}, \bar{H});

[Statements]

RETURN;

END TIME_RADIUS;

NOTE: "Call-By-Name", "Call-By-Value"
EXAMPLE OF A FUNCTION

ABLE: N = TRACER(A+B);
GO TO BAKER;

TRACER: FUNCTION(Q);
DECLARE Q MATRIX(A,*);
IF TRACE(Q) > 100 THEN
  RETURN (Q^{-1} + Q + QQ + QQQ)
ELSE RETURN(0);
END TRACER;

NOTE: "CALL BY VALUE", "run-time" dimensions
PROGRAMMING REQUIREMENTS FOR
REAL TIME SPACE APPLICATIONS

Scheduling and Tasking

Software performs time critical functions and responds to interrupts in a complex environment requiring the capability to schedule, control and synchronize tasks.

Recovery From Error Conditions

Techniques are required to protect and enable system to "continue" after detection of unexpected error condition.

Common Memory Sharing and Control

Techniques are required to dynamically control the use of common data elements among tasks in the environment.
EXAMPLE OF HAL REAL-TIME CONTROL

ENDMANU and ENDMEAS are programmer-defined events.

INTERMETRICS
REAL TIME STATEMENT EXAMPLES

SCHEDULE TARGETING PRIORITY(3);

SCHEDULE RADAR ON R_SUPT PRIORITY(PRIO + 2) RADAR_PROG;

IF TRACKFLAG = ON THEN SCHEDULE AUTOMANEUVER IN 5;

ELSE WAIT UNTIL (TIME + 5);

SCHEDULE STEERING AT(IGNITION + 3) PRIORITY(10) INDEPENDENT;

TERMINATE RADAR_PROG;

WAIT FOR OK;

SIGNAL OK;
CONTROL OF SHARED DATA

EXAMPLE 1: READ AND WRITE CONFLICTS

A: TASK;
M = N + P;
CLOSE A;

UPDATE;
CONTROL
CLOSE;

B: TASK;
N = X Y;
CLOSE B;

UPDATE;
CLOSE;

EXAMPLE 2: UPDATE CONFLICTS

A: TASK;
Y = Y - X;
CLOSE A;

UPDATE;
CONTROL
CLOSE;

B: TASK;
Y = Y - Z;
CLOSE B;

UPDATE;
CLOSE;

NOTES:
1. B "INTERRUPTS" A IN BOTH CASES

2. #1 TASK A RESUMES USING OLD AND NEW VALUES FOR N

3. #2 TASK A RESUMES "Clobbering" the value for Y set by Task B
ERROR CONDITION STATEMENTS EXAMPLES:

ON ERROR_12  GO TO ABLE;

ON ERROR_1 TO 5  GO TO BAKER;

ON ERROR_4  SYSTEM;

E_RUPT ERROR_6;
SUMMARY

* HAL emphasizes reliability
  * Readability
  * Data protection

* HAL is a full-capability language
  * Includes all data types
  * Real-time control statements
  * Supports on-board computer software
  * Floating- or fixed-point syntax
  * Supports ground, checkout, simulation software

* Schedule of Events
  * First version delivery to MSC in June, 1971
  * Development to continue compatible with Shuttle schedule
  * Object-code-module required for selected on-board-computer

INTERMETRICS

SLIDE 14
A.2 LONGER HAL COURSE
HAL Data Operations - 1

Arithmetic
All common operations including:
* Vector dot, cross and outer products
* Matrix multiplication, inverse transpose
* Integer mathematics
* Combined integer-scalar operation

Bit String
Logical AND, OR, NOT, of:
* Long bit strings, bit-by-bit
* Single bit "booleans"

Concatenation

Character String
Concatenation of characters and data into messages

Arrays
Most valid element-by-element operations apply to arrays
Comparisons

A comparison of data always results in a single TRUE or FALSE answer.

* Absolute comparison

VECTOR, MATRIX, ARRAY, STRUCTURE

=  \ NOT=

* Absolute and Relative Comparisons

scalar

integer

bit

character

=  \ NOT=

\leq

\geq

\not<

\not>
EXAMPLES OF DATA OPERATIONS - I

Arithmetic Operations

\[ I = (-J)^3 + K(3+J); \quad \text{---- all integers} \]

\[ A = \frac{P}{R} + R^P - \mathbf{V}^* \mathbf{M} \mathbf{V}; \quad \text{---- scalars, vectors, matrices} \]

\[ \mathbf{E} = -\mathbf{F}^* \mathbf{V} + 5 \mathbf{M} \mathbf{V} + A(\mathbf{V} \cdot \mathbf{F})^2 \mathbf{F} + \frac{\mathbf{F}}{(\mathbf{V} \cdot \mathbf{M})}; \quad \text{---- scalars, vectors, matrices} \]

\[ \mathbf{C} = -\mathbf{M}^* \mathbf{M}^{-1} + \mathbf{V} \mathbf{V}/A - (\mathbf{M} + \mathbf{N})^T; \quad \text{---- scalars, vectors, matrices} \]

\[ A = I/J + B J + J^{-6.4}; \quad \text{------- integers, scalars} \]
EXAMPLES OF STRING OPERATIONS

Bit String

\[
D = B \text{ AND } C;
\]

\[
D = A \text{ OR } (B \text{ AND } C);
\]

\[
A = D | \text{ NOT } B | (B \text{ AND } C);
\]

Character String

\[
C = 'P\text{LEASE}' | 'H\text{ELP}';
\]

\[
D = 'T\text{HE A\text{NS. IS'}} | X | 'N\text{.M.}';
\]
EXAMPLES OF ARRAY OPERATIONS

"Two-array" operations:

- \([P]/[A]\), \([\vec{F}] \ast [\vec{V}]\), \([R]^{[P]}\), \([A]\) OR \([B]\)

One-array operations:

- \(-P/[A]\), \(\vec{F} \ast [\vec{V}]\), \(R^{[P]}\), \([A]\) OR \(B\)
EXAMPLES OF COMPARISON OPERATIONS

IF $I > J$ THEN ------

IF $A \text{ NOT} < (X^2 - 5 \bar{V} \cdot \bar{V})$ THEN ------

DO WHILE $S = (A \text{ AND } B)$ ------

IF $M = N$ THEN------

DO WHILE $[A] \text{ NOT} = [B]$ ------
HAL Explicit Declarations

* In general, all data must be declared by declare statements (with the exception of those permitted by implicit declarations).

* The declare statement specifies the name, organization, type and attributes of data quantities.

Keywords used in declare statements:

<table>
<thead>
<tr>
<th>Organization</th>
<th>Type</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARRAY</td>
<td>INTEGER</td>
<td>PRECISION</td>
</tr>
<tr>
<td></td>
<td>SCALAR (optional)</td>
<td>INITIAL</td>
</tr>
<tr>
<td></td>
<td>VECTOR</td>
<td>CONSTANT</td>
</tr>
<tr>
<td></td>
<td>MATRIX</td>
<td>STATIC</td>
</tr>
<tr>
<td></td>
<td>BIT</td>
<td>AUTOMATIC</td>
</tr>
<tr>
<td></td>
<td>CHARACTER</td>
<td>LOCKTYPE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DENSE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ALIGNED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VARYING</td>
</tr>
</tbody>
</table>
EXAMPLES OF EXPLICIT DECLARATIONS

1. DECLARE I INTEGER INITIAL (65);
   I is an integer with an initial value = 65.

2. DECLARE X PRECISION (8) AUTOMATIC INITIAL (6.061);
   X is a floating point scalar with at least 8 significant decimal digits.

3. DECLARE A ARRAY (5,3,4) VECTOR (6) PRECISION (10);
   A is a 5x3x4 array. Each element is a 6 dimensional vector with components represented to 10 significant decimal digits.

4. DECLARE MATRIX (3,4) INITIAL (0) AUTOMATIC
   A, B, C PRECISION (10);
   A, B, and C are all (3,4) matrices with automatic storage. All components are set to zero.

5. DECLARE A PRECISION (10,15)
   A is a fixed point scalar with 10 integer bits and at least 15 fractional bits (i.e. maximum value < $2^{10}$, granularity $\leq 2^{-15}$).
INDEX OPERATORS

1. The "TO" operator

Selects a subset of elements from element-i "TO" element-j.

For example: $A_1 \text{ TO } 10$

2. The "AT" operator

Selects a subset of N-elements starting at element-i.

For example: $A_{10} \text{ AT } 1$

3. The number of elements in any "partition" must be known at compile-time.
EXAMPLES OF INDEXING - I

1. Vectors and Matrices (given $V$, $M$)

$V_2$ ------- scalar element,

$V_1$ TO 5 ------ sub-vector,

$M_{2,3}$ ------- scalar element,

$M_{*,1}$ ------ vector element,

$M_{*,1}$ ------ vector element,

$M_{3,1}$ AT $P$, $3$ AT $Q$ ------ sub-matrix

2. Bit and Character Strings (given $S$, $C$)

$S_3$ ------- single bit,

$S_2$ TO 10 ------ sub-string,

$S_6$ AT $P$ ------ sub-string

$C_3$ TO $\#$ ------ sub-string,
3. Arrays (given $[A]$, a two-dimensional array of matrices)

$[A]_{1 \text{ TO } 4, \ 3 \text{ TO } 6}$: sub-array

$[A]_{P, \ Q}$: an array of scalar elements

$[A]_{*, \ *, \ 2} \equiv [\bar{A}]_{*, \ 2}$: sub-array of vector elements

4. Array of Bit Strings

$[A]_{3 \text{ TO } 5, \ *, \ 1 \text{ TO } 6}$: sub-array of sub-strings

$A_{6, \ 4, \ 3}$: one particular bit
DO - STATEMENTS

• DO - statements block out a set of statements which are to be treated as a single unit.

• There are four types of DO - statements

1. Simple DO-END
2. Iterative DO-FOR
3. Iterative DO-WHILE
4. Selective DO-CASE
EXAMPLES OF DO-STATEMENTS - I

Simple DO-END

IF X>5 THEN BAKER: DO;

B A = B;
C = D;
GO TO ABLE;
END BAKER;

ELSE CHARLIE: DO;

\bar{z} = \hat{M} \vec{v};
\bar{F} = \vec{v} \times \bar{z};

IF Y = 0 THEN GO TO OUT;

END CHARLIE;
EXAMPLES OF DO-STATEMENTS - II

1. Iterative DO-FOR

ABLE: DO FOR I = P TO (N/S) BY L WHILE N>0;  
limits and increment are computed once.

\[ X = Y^2 + A_I; \]
\[ N = N - .006 X; \]
\[ P = 1; \quad S = 2; \quad L = 3; \]

END ABLE;

2. Iterative DO-WHILE

ABLE: DO WHILE (X > Y AND GO_FLAG = ON);  
X, Y and GO_FLAG are recomputed.

\[ X = Y^2 + P \cdot \log(Z); \]
\[ \text{GO_FLAG = TRAKFLAG OR NAV_FLAG;} \]

[Statements]

END ABLE;
EXAMPLE: SEARCHING AN ARRAY OF DATA

The final phase reference for Apollo reentry:

DECLARE ARRAY (13) VREF CONSTANT (994, 2103, 3922,...);
DECLARE ARRAY (13) RDOTREF CONSTANT (-690.0, -719,...);
DECLARE ARRAY (13) DREFR CONSTANT (41.15, 60, 81.5,...);
;
;
;
etc.

INTERPOLATE:  I = 0;

DO WHILE (VREF_I NOT< V) AND (V NOT< VREF_{I+1});
  I = I + 1;
END;

GRAD = (V - VREF_I)/(VREF_{I+1} - VREF_I);

RDOTREF_V = RDOTREF_I + GRAD (RDOTREF_{I+1} - RDOTREF_I);

GO TO CONTINUE;
EXAMPLES OF DO-STATEMENTS - III

Selective DO-CASE (Computed DO-Statement)

ABLE: DO CASE N;

\[
X = y^2;
\]

CASE 1

BAKER: DO CASE P;

\[
F = A + B;
\]

CASE 1

\[
\bar{G} = \bar{M} \bar{V};
\]

CASE 2

END;

GO TO CHARLIE;

CASE 3

\[
\bar{Z} = \bar{W} + \bar{E};
\]

CASE 4

END ABLE;
EXAMPLES OF IF-STATEMENTS

1. Simple:
   \[
   \text{IF } X = 5 \text{ AND } Y > 6 \text{ THEN ABLE: GO TO PLACE;}
   \]
   \[
   \quad \text{ELSE GO TO TRY AGAIN;}
   \]

2. Complex:
   \[
   \text{IF } X = 5 \text{ THEN IF } Y > 6 \text{ THEN IF } B \text{ OR } C \text{ THEN } Z = \* V;
   \]
   \[
   \quad \text{ELSE CHOICE: } Z = \* M^{-1} V;
   \]

3. More Complex:
   \[
   \text{IF } S = (A \text{ OR } B) \text{ THEN IF } X > 5 \text{ AND } Y > 6 \text{ THEN GO TO OUT;}
   \]
   \[
   \quad \text{ELSE IF } [A] \neq [B] \text{ THEN } [A] = [C];
   \]
   \[
   \quad \text{ELSE IF } ----- \text{ THEN } -----; \text{ ELSE IF } ----- \text{ THEN } -----;
   \]
   \[
   \quad \text{ELSE GO TO TRY AGAIN;}
   \]

note: ELSE always refers to immediately preceding IF.
SELECTIVE INCLUSION OF OUTER-NAMES

ABLE:

PROGRAM;
DECLARE A,B,C,D,E,F;

BAKER: PROCEDURE;
OUTER B,D,F;
DECLARE A,E;

- Only B,D,F are recognized outer names. (A,C,E are "rejected").
- A,E are defined locally.

Note: COMPOOL variable-names may be accepted, rejected and/or locally defined by combinations of DECLARE and OUTER statements. In order to use implicit declarations within a block (except for PROGRAM-level) an OUTER-statement must be present.
APPENDIX B.
HAL-in-HAL Detailed Description and Listing

B.1 INTRODUCTION

The output from the HAL-in-HAL experiment consists of the following:

1. The HAL program listing, symbol table, and cross reference
2. The output of the HAL program execution
3. A listing of the source data read by HAL-in-HAL (a sample HAL program)

B.2 HAL-in-HAL PROGRAM DESCRIPTION

This section will describe the general function of each of the routines in HAL-in-HAL. Refer to the program listing for specific details.

B.2.1 STREAM (Statements 100-542)

The overall functions of the STREAM procedure are as follows:

1. Convert the multi-line format of the input cards to a one-line format, which is required by the scanning and syntactic analysis routines.
2. Process Comment and Heading cards to aid readability of the source program, and also to enable certain compiler toggles for assisting the person who is debugging the compiler.
3. Eliminate HAL in-line comments (strings contained between /* and */).
4. Perform substitutions for replace type strings (not demonstrated).

To convert input to one-line format requires the following:
1. Enclosure of each level of subscripting in parentheses, preceded by the dollar-sign character ($).

Ex.

\[ M S_{l_1} = S_{2_{ix_i}} \]

\[ S \]

becomes

\[ S_{l_1}$^\$(i) = S_{2$(ix$(i))}; \]

2. Enclosure of each level of exponentiation in parentheses, preceded by two asterisks (**) .

Ex.

\[ E^{2}^{2} \]

\[ E^{2} \quad I \]

\[ M S_{2} = X \]

becomes

\[ S_{2^{**}(2)} = X^{**}(I^{**}(2)); \]

STREAM contains ten local subroutines which assist it in performing its function. They are local because they are of no value outside of STREAM. The non-local procedures are general interest routines, which are useful at levels other than within the STREAM procedure.

B2.2 CARD_TYPE (Statements 26-33)

CARD_TYPE is a function which receives as input the first character from an input card and returns an integer typifying the card in one of five classes.

B2.3 CHAR_INDEX (Statements 34-44)

CHAR_INDEX locates one string within another, returning the relative position of the desired substring if found, and 0 otherwise.

B2.4 PAD (Statements 45-53)

The PAD function forces a varying character string to a minimum specified fixed length by appending trailing blanks.
Its primary function is for WRITE list items.

B2.5 I FORMAT (Statements 54-61)

The I FORMAT function first converts a number to a character string, and then adds high order blanks to force a right justified integer string of a specified fixed length. This routine is also primarily for WRITE list items.

B2.6 ERRORS (Statements 62-82)

ERRORS both prints error messages when reported, and saves a record of their occurrence for later reporting. It also will terminate the compilation if either too many or too severe errors occur during compilation.

B2.7 PROCESS_COMMENT (Statements 116-133)

This routine processes heading cards, as well as looking for special debugging directives on comment cards.

B2.8 STACK_RETURN_CHAR (Statements 134-144)

This routine locates an available position in the return stack and records both a count and the character to be added to the output stream to formulate one-line output out of multi-line input.

B2.9 READ_CARD (Statements 145-157)

This routine reads the next input card and prints the card previously read. (This is because a group is only defined by the next non-group card.) It also counts the input cards and checks for an end of input condition.

B2.10 ORDER_OK (Statements 158-189)

This routine verifies that cards are in the proper sequence to formulate a proper HAL group. It also signals when a group is completed.
B2.11 COMMENT (Statements 190-201)

This routine removes '/* */' type comments from E and S lines, when they exist.

B2.12 SCAN_CARD (Statements 202-220)

This routine scans E and S cards for non-blank characters, compressing multiple lines into one line, with an indicator recording which level the character appeared on. If an overlap occurs, the one closest to the M line is retained, and a diagnostic is issued.

B2.13 COMP (Statements 221-244)

This routine is called when either an E line or S line is first encountered in a group. It keeps reading cards and calling SCAN until an entire E or S group is compressed into a single line as described in B2.12.

B2.14 GET_GROUP (Statements 245-297)

This routine is called to assemble a complete group, which consists of an M line and one or more E and/or S lines, formulating as output a single E line, M line, and S line, with corresponding indicators.

B2.15 CHOP (Statements 298-306)

This routine advances the M line character index by 1, forcing a new group to be read when the M line termination is reached. The information concerning the last character on the previous card is retained.

B2.16 STACK (Statements 307-325)

This routine builds on Exponent or Subscript stack corresponding to a single blank field on an M line; i.e., those subscripts and/or exponents related to a specified variable or function. This is in preparation for outputting from STREAM within stacked Return characters (see B2.8).
This procedure invokes STACK for building both the E and S stacks for a single blank field, including M line comments as blank fields. Residue blanks for which no E or S line characters exist are treated as blank fields by the scanner (blank fields by the scanner (blank is a legal delimiter in HAL).

B.3 DESCRIPTION OF HAL-IN-HAL OUTPUT

The output of the HAL program is interpreted thusly. The program reads in a group of data cards. A group can consist of:

1. a single M line
2. one or more E lines followed by a single M line
3. a single M line followed by one or more S lines
4. one or more E lines followed by a single M line followed by one or more S lines

Each group is then converted into one line of output to the scanning routine. A group of type 1 is transmitted directly except for elimination of redundant blanks. A group of the other three types involves processing of S line and/or E line stacks and the addition of the appropriate subscript and/or exponent enclosures (subscripting is performed first if the M line identifier has both a subscript and an exponent attached). As the scanning routine continuously calls STREAM, identifier tokens are formed. All identifier and special character tokens are printed as they are encountered, including identifier over punches. When the token is a blank, a count of the blanks scanned is printed.

The full output consists of the following:

1. a printout of the entire card group just read, complete with card numbering
2. a printout of the individual tokens encountered within the group just read (signalled by TOKEN= or BLANKS=)
3. a printout of the combined one-line format and any possible over-punch characters whenever a semi-colon (;) is returned by STREAM. This represents a complete HAL statement as seen by the scanning routine (signalled by OVER and MAIN in succession).
This sequence is repeated until the input is exhausted (signalled by a "?" for this test). Note in the TOGGLE sequences where the subscript and exponent enclosures are added to the characters on the actual input cards.


HAL Compilation -- Phase 1 -- Intermetrics, Inc.

1 MHALNHAL: PROGRAM:
2 C1 & P C D E F G
3 C1 THE FOLLOWING GROUP OF DECLARES ARE ONLY TEMPORARY
4 M1 DECLARE P BY 'DECLARE';
5 M1 R FALSE BY 'O'; R TRUE BY '1'; R BIT_1 BY 'INTEGER';
6 M1 IF\/NOT BY 'IF O ='; R IF BY 'IF 1 =';
7 M1 R CUT BY 'WRITE(5)';
8 M1 R FOREVER BY 'WHILE 1 = 1';
9 M1 DEFAULT INTEGER;
10 M1 DECLARE XTO CHARACTER(70) INITIAL (' ');
11 M1 DECLARE CHARACTER(255) VARYING, BUILT, BUILT_UP, BUILT_TOKEN, BUILT_O_P;
12 M1 DECLARE BLANK_FLAG BIT_1 INITIAL(FALSE);
13 M1 DECLARE INTEGER INITIAL(0),
14 M1 ERROR_COUNT, MACRO_POINT, MACRO_LIMIT,
15 M1 OLD_LEVEL, NEW_LEVEL,
16 M1 MAX_SEVERITY, STATEMENT_SEVERITY,
17 M1 SAVE_SEVERITY ARRAY(100),
18 M1 SAVE_LINE ARRAY(100), PREVIOUS_ERROR, I;
19 M1 DECLARE CCVFILING BIT_1 INITIAL(TPUE);
20 M1 DECLARE INTEGER, TIME1, TIME2;
21 M1 DECLARE MACRO_STREAM CHARACTER(255) VARYING;
22 M1 DECLARE MACRO_FOUND BIT_1 INITIAL(FALSE);
23 M1 DECLARE CARD_COUNT INTEGER INITIAL(-1);
24 M1 DECLARE DISASTER LABEL;
25 M1 DECLARE NEXT_CHAN CHARACTER(1);
22 M1 DECLARE OVER_FUNCH CHARACTER(1):
23 M1 DECLARE BLANK_COUNT INTEGER INITIAL(0);
24 M1 DECLARE CONTROL ARRAY(10) BIT(37):
25 M1 DECLARE TGGIFS CHARACTER(10) INITIAL('1234567890');

THE ARRAY CARD_TYPE IN XFL IS REPLACED BY THIS FUNCTION

26 M1 CARD_TYPE:
27 M1 FUNCTION(SELECT) INTEGER:
28 M1 CELEFA SELECT CHARACTER(1):
29 M1 IF SELECT = 'K' OR SELECT = ' ' THEN RETURN 2;
30 M1 IF SELECT = 'S' THEN RETURN 3;
31 M1 IF SELECT = 'E' THEN RETURN 1;
32 M1 IF SELECT = 'C' OR SELECT = 'M' OR SELECT = 'H'
33 M1 THEN RETURN 4;
34 M1 RETURN 0;
35 M1 CLOSE CARD_TYPE;

THE CHAR_INDEX FUNCTION IS THE SAME AS THE INDEX BUILT IN FUNCTION

36 M1 CHAR_INDEX: FUNCTION(STRING, PATTERN) INTEGER:
37 M1 DECLARE CHARACTER(*), STRING, PATTERN;
38 M1 DECLARE INTEGER, I, J, K;
39 M1 J = LENGTH(STRING);
40 M1 K = LENGTH(PATTERN);
41 M1 IF K > J THEN RETURN 0;
42 M1 ELSE DC FOR I = 1 TO J-K+1:
43 M1 IF STRING(I AT I) = PATTERN THEN RETURN 1;
44 M1 END;
HAL COMPILATION -- PHASE 1 -- INTERNETRICS, INC.

47 MI RETURN 0;
48 MI CLOSE CHAR_INDEX;
49 MI IF HERE IS PAD A FUNCTION FROM HALPASS!
50 MI PAD: FUNCTION (STRING,WIDTH) CHARACTER(255) VARYING;
51 MI DECLARE CHARACTER(*), STRING;
52 MI DECLARE CHARACTER(255) VARYING, TEMP_STRING;
53 MI DECLARE INTEGER, L, WIDTH;
54 MI L = LENGTH(STRING);
55 MI IF L < WIDTH THEN
56 MI TEMP_STRING = STRING || X70S(1 TO WIDTH-L);
57 MI ELSE TEMP_STRING = STRING;
58 MI RETURN TEMP_STRING;
59 MI CLOSE PAD;
60 MI IF HERE IS THE FUNCTION I_FORMAT FROM HALPASS!
61 MI I_FORMAT: FUNCTION(NUMBER,WIDTH) CHARACTER(*);
62 MI DECLARE CHARACTER(255) VARYING, STRING;
63 MI DECLARE CHARACTER(255) VARYING, STRING;
64 MI DECLAR INTGER, L, NUMBER, WIDTH;
65 MI STRING = NUMBER;
66 MI L = LENGTH(STRING);
67 MI IF L < WIDTH THEN
68 MI STRING = X70S(1 TO WIDTH-L) || STRING;
69 MI RETURN STRING;
70 MI CLOSE I_FORMAT;
71 MI THE FOLLOWING IS THE ERRER PROCEDURE FROM PASS1.
62 M1 ERRORS: PROCEDURE (MESSAGE,SEVERITY):
  C1 PRINTS AND ACCOUNTS FOR ALL ERRORS
63 M1 DECLARE MSG CHARACTER(256) VARYING;
64 M1 DECLARE MESSAGE CHARACTER(*);
65 M1 DECLARE SEVERITY INTEGER;
66 M1 ERROR_COUNT = ERROR_COUNT + 1;
67 M1 MSG = '***** ERROR # ' || ERROR_COUNT || ' OF SEVERITY ' ||
68 M1  SEVERITY || ' ' || MESSAGE:
69 M1 IF ERROR_COUNT > 1 THEN
70 M1  MSG = MSG || ' LAST ERROR ON LINE ' || PREVIOUS_ERROR;
71 M1 WRITE(6)MSG || ' ******';
72 M1 SAVE_SEVERITY( ERROR_COUNT ) = SEVERITY:
73 M1 SAVE_LINES( ERROR_COUNT ) = CAPS_COUNT;
74 M1 IF ERROR_COUNT >= 99 THEN GO:
75 M1 IF ERROR_COUNT = 100 THEN
76 M1 WRITE(6) 'TOO MANY ERRORS: COMPILATION ABORTED. ';
76 M1  IFF COMPILING THEN COMPILING = FALSE;
77 M1 ELSE GO TO DISASTER; /* THEN EAT IT THERE */
77 M1 END;
78 M1 IF SEVERITY > MAX_SEVERITY THEN MAX_SEVERITY = SEVERITY;
79 M1 IF SEVERITY > STATEMENT_SEVERITY THEN
80 M1 STATEMENT_SEVERITY = SEVERITY;
80 M1 IF SEVERITY > 2 THEN IFF COMPILING THEN
81 M1 COMPILING = FALSE;
82 M1 ELSE GO TO DISASTER;
83 M1 END OF PASS1 ERROR
STMT: SOURCE.

82 M1 CLCSE ERRORS; /* CLOSING ERRORS AND RETURNING. */
83 M1 PRINT_SUMMARY: PROCEDURE;
84 M1 WRITE(6) CARD_COUNT II ' CARDS WERE PROCESSED';
85 M1 IF ERROR_COUNT = 0 THEN WRITE(6) ' NO ERRORS WERE DETECTED. ';
86 M1 ELSE IF ERROR_COUNT > 1 THEN Do;
87 M1 WRITE(6) ' ERROR_COUNT II ERRORS WERE DETECTED. ';
88 M1 ' THE LAST ERROR WAS ON LINE II PREVIOUS_ERROR:;
89 M1 WRITE(6) '*****SUMMARY OF DETECTED ERRORS.*****:;
90 M1 CC FOR I = 1 TC ERROR_COUNT;
91 M1 WRITE(6) 'ERRORS II II ON LINE II ';
92 M1 SAVE_LINES II ' OF SEVERITY II ';
93 M1 SAVE_SEVERITY II ' ';
94 M1 END;
95 M1 END;
96 M1 ELSE WRITE(6) 'ONE ERROR WAS DETECTED WHICH OCCURRED ON LINE II ';
97 M1 PREVIOUS_ERROR II OF SEVERITY II SAVE_SEVERITY II ' ';
98 M1 TIME2 = TIME;
99 M1 T = TIME2-TIME1;
100 M1 WRITE(6) 'CARDS-PROCESSING RATE: II 6000 CARD_COUNT/I II ';
101 M1 ' CARDS PER MINUTE. ';
102 M1 WRITE(6) ' CLCCK TIME IS II TIME2;
103 M1 RETURN;
104 M1 CLOSE PRINT_SUMMARY;
105 M1 STREAM: PROCEDURE;
106 M1 THIS PROCEDURE FILLSS THE VARIABLES NEXT_CHAR,
107 M1 ARROW, AND OVER_HUNT.
<table>
<thead>
<tr>
<th>STMT</th>
<th>SOURCE</th>
<th>LINE</th>
<th>CURRENT SCOPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>DECLARE CHARACTER(255) VARYING, F_LINE, S_LINE, M_LINE;</td>
<td>160</td>
<td>STREAM</td>
</tr>
<tr>
<td>102</td>
<td>DECLARE CHARACTER(901), SAVE_CARD, CURRENT_CARD;</td>
<td>161</td>
<td>STREAM</td>
</tr>
<tr>
<td>103</td>
<td>DECLARE BLANKS CHARACTER(128) INITIAL(' ');</td>
<td>162</td>
<td>STREAM</td>
</tr>
<tr>
<td>104</td>
<td>DECLARE E_LINE_ERR CHARACTER(50) VARYING</td>
<td>163</td>
<td>STREAM</td>
</tr>
<tr>
<td>105</td>
<td>INITIAL('E_LINE CHARACTER MORE THAN 1 LINE ABOVE PRECEDING CHARACTER');</td>
<td>164</td>
<td>STREAM</td>
</tr>
<tr>
<td>106</td>
<td>DECLARE ERR_PUNCH CHARACTER(127) INITIAL('SOURCE PROGRAM OUT OF ORDER');</td>
<td>165</td>
<td>STREAM</td>
</tr>
<tr>
<td>107</td>
<td>DECLARE CHARACTER(11), PREV_CARD, SAVE_NEXT_CHAR, SAVE_ERR_PUNCH;</td>
<td>166</td>
<td>STREAM</td>
</tr>
<tr>
<td>108</td>
<td>DECLARE INTEGER INITIAL(0), LAST_E_IND, LAST_S_IND, E_BLANKS, M_BLANKS,</td>
<td>167</td>
<td>STREAM</td>
</tr>
<tr>
<td></td>
<td>S_BLANKS, SP, SP, TEXT_LIMIT, E_COUNT, LAST_E_COUNT, S_COUNT,</td>
<td>168</td>
<td>STREAM</td>
</tr>
<tr>
<td>109</td>
<td></td>
<td>169</td>
<td>STREAM</td>
</tr>
<tr>
<td>110</td>
<td>DECLARE ARRAY(256) INTEGER INITIAL(0), E_INC, S_INC, E_INDICATOR,</td>
<td>170</td>
<td>STREAM</td>
</tr>
<tr>
<td></td>
<td>S_INDICATOR;</td>
<td>171</td>
<td>STREAM</td>
</tr>
<tr>
<td>111</td>
<td>DECLARE BIT_1 INITIAL(FALSE), RETURNING_E, RETURNING_M, RETURNING_S,</td>
<td>172</td>
<td>STREAM</td>
</tr>
<tr>
<td></td>
<td>END_GROUP, M_COMEKT, ARRCW_FLAG;</td>
<td>173</td>
<td>STREAM</td>
</tr>
<tr>
<td>112</td>
<td>DECLARE BIT_1 INITIAL(TRUE), FIRST_CALL_TC_STREAM;</td>
<td>174</td>
<td>STREAM</td>
</tr>
<tr>
<td></td>
<td>DECLARE ARRAY(3) CHARACTER(1), TYPE_CHAR;</td>
<td>175</td>
<td>STREAM</td>
</tr>
<tr>
<td>113</td>
<td>DECLARE ARRAY(3) INTEGER INITIAL(0), RETURN_CHAR;</td>
<td>176</td>
<td>STREAM</td>
</tr>
<tr>
<td></td>
<td>DECLARE CHARACTER(255) VARYING, E_STACK, S_STACK;</td>
<td>177</td>
<td>STREAM</td>
</tr>
<tr>
<td></td>
<td>DECLARE INPUT_PAC CHARACTER(23) INITIAL</td>
<td>178</td>
<td>STREAM</td>
</tr>
<tr>
<td>114</td>
<td>(&quot;M /&quot; EOF EOF EOF);</td>
<td>179</td>
<td>STREAM</td>
</tr>
</tbody>
</table>
HAL Compilation -- Phase 1 -- Intermetrics, Inc.

STMT      SOURCE
115 M1  GO TO STREAM_START;
116 M1  PROCESS_COMMENT:  PROCEDURE;
117 M1  DECLARE K CHARACTER (1):  
118 M1  DECLARE J INTEGER;  
119 M1  IF CURRENT_CARDS = 'H' THEN
120 M1  WRITE (A): LINE (1), CURRENT_CARDS (2 TO 4) /* ISSUE A NEW HEADER*/
121 M1  ELSE
122 M1  IF CURRENT_CARDS = 'C' THEN
123 M1  DC FOR I=1 TO TEXT_LIMIT-1:  
124 M1  IF CURRENT_CARDS = ' ' THEN DO:
125 M1  K = CURRENT_CARDS (I+1);
126 M1  J = CHAR_INDEX (Toggles, K);
127 M1  IF J = 0 THEN DO:
128 M1  IF I < TEXT_LIMIT-1 THEN
129 M1  K = CURRENT_CARDS (I+2):
130 M1  ELSE GC TO COMPLEMENT;
131 M1  IF K = '"' THEN CONTROL = TRUE;
132 M1  ELSE IF K = '-' THEN CONTROL = FALSE;
133 M1  ELSE COMPLEMENT: CONTROL = NOT CONTROL;
134 M1  END;
135 M1  END;
136 M1  END;
137 M1  CLOSE PROCESS_COMMENT;
**TERM E TR I C S**

134 | STACK_RETURN_CHAR:
134 | PROCEDURE(NUMBER,CHAR);:
135 | DECLARE INTEGER, NUMBER, I:
136 | DECLARE CHAR CHARACTER(1);
137 | DC FOR I = 1 TO 3:
138 | IF RETURN_CHAR = 0 THEN DO:
139 | I:
140 | RETURN_CHAR = NUMBER;
140 | I:
140 | TYPE_CHAR = CHAR;
140 | I:

C) THE FOLLOWING STATEMENT IS FOR DEBUGGING PURPOSES ONLY.
C) GLT 'STACKED'[1][CHAR][1][NUMBER][1] = INDEX([1][1][1][1]);

141 | RETURN;
142 | END;
143 | END;
144 | CLOSE STACK_RETURN_CHAR;

C) READ_CARD:

145 | PROCEDURE:
146 | DECLARE END_OF_INPUT BIT_1 INITIAL(FALSE);
147 | IFF END_OF_INPUT THEN DO:
148 | CURRENT_CARD = INPUT_PAC;
149 | RETURN;
150 | END;
151 | READ(S) CURRENT_CARD;
C) END_OF_INPUT = TRUE;
152 | CARD_COUNT = CARD_COUNT + 1;
HAL COMPILED -- PHASE 1 -- INTERMETRICS, INC.

STMT
153 M) IF CARD_COUNT.NOT = 'O' THEN DO;
154 M) WRITE(6) I_FORMAT(CARD_COUNT, 4)
154 M) [I I I I SAVE.CARDS] I I 'I' II SAVE.CARDS(2 TO #) I I 'I'II CARD_COUNT;
155 M) END;
156 M) SAVE.CARD = CURRENT.CARD;
157 M) CLOSE READ.CARD;
158 M) ORDER_OK:
159 M) FUNCTION(TYPE) BIT_1;
160 M) DECLARE TYPE CHARACTER(1);
161 M) CC CASE CARD_TYPE(CURRENT.CARDS1) + 1;
162 M) DO: /* CASE 1 -- ILLEGAL CARD TYPE*/
163 M) END_GROUP = FALSE;
164 M) RETURN FALSE;
165 M) END; /* OF CASE 1*/
166 M) /* CASE 2 -- E CARD*/
167 M) E.CARD:
168 M) DD;
169 M) IF CARD_TYPE(TYPE) = 2 OR
170 M) CARD_TYPE(TYPE) = 3 THEN END_GROUP = TRUE;
171 M) ELSE END_GROUP = FALSE;
172 M) RETURN TRUE;
173 M) END; /* CASE 2*/
174 M) /* CASE 3 -- M CARD*/ GC TO E.CARD;
175 M) DO: /* CASE 4 -- S CARD*/
176 M) END_GROUP = FALSE;
177 M) IF CARD_TYPE(TYPE) = 2 OR
178 M) /* CASE 4 */
STMT | SOURCE | LINE | CURRENT SCOPE
---|---|---|---
177 M | CARD_TYPE(TYPE) = 3 THEN RETURN TRUE; | 271 | ORDER_OK
174 M | ELSE RETURN FALSE;
175 M | END: /* CASE */
176 M | CC: /*CASE 5--& COMMENT*/
177 M | IF CARD_TYPE(TYPE) = 2 OR
177 M | CARD_TYPE(TYPE) = 3 THEN END_GROUP = TRUE;
178 M | ELSE END_GROUP = FALSE;
179 M | IF CURRENT_CARD$1 = 'P' THEN DO;
180 M | IF TYPE = 'C' THEN RETURN TRUE;
181 M | ELSE RETURN FALSE;
182 M | ENC;
183 M | ELSE DO;
184 M | IF CARD_TYPE(TYPE) = 1 THEN RETURN FALSE;
185 M | ELSE RETURN TRUE;
186 M | ENC;
187 M | ENC; /* CASE */
188 M | ENC; /*CF CO CASE*/
189 M | CLOSE ORDER_OK;
190 M | COMMENT:
190 M | FUNCTION BIT_1;
191 M | IF CURRENT_CARD$CP = '/' THEN
191 M | IF CP < TEXT_LIMIT THEN
191 M | IF CURRENT_CARD$CP = '*' THEN DO:
191 M | LOOK FOR END OF COMMENT.
192 M | DC FOR CP = CP+2 TO TEXT_LIMIT-1;
193 M | IF CURRENT_CARD$CP = '.' THEN
PROCEDURE(TYPE, COUNT) ASSIGN(LIN, INDICATOR);

DECLARE INDICATOR ARRAY(256) INTEGER;
DECLARE INTEGER, TYPE, COUNT;
DECLARE LIN CHARACTER(*);
DO FOR CP = 2 TO TEXT_LIMIT;
IF CURRENT_CHARACTER NOT = ' ' THEN GO;
IF COMMENT THEN GO TO CONTINUE;
IF LINC = NOT = ' ' THEN
CASE TYPE + 1; /*HAL DO CASES START WITH 1*/
CASE 1# CALL ERRORS('OVERLAPPING E-LINE CHARACTERS',1);
DO; /* CASE 2*/
CALL ERRORS('OVERLAPPING S-LINE CHARACTERS',1);
GO TO CONTINUE;
END; /*CF CASE 2*/
PROCEDURE TYPE ASSIGN (LIN, INDICATOR, COUNT);

DECLARE PCINT CHARACTER(1);
DECLARE INTCER, COUNT, TPRE;

CHARACTER(256) INTG, INDICATCR;

IF TYPE = 1 THEN PCINT = 'S';
ELSE PCINT = 'E';
COUNT = 1;
DO FOREVER;
CALL SCAN_CARD(TYPE, COUNT) ASSIGN (LIN, INDICATOR);

CALL READ_CARD;
IF CURRENT Cards1 NOT = PCINT THEN DO;
AC MORE OF THIS TYPE CARD.

IF NOT CRDER_CK(PCINT) THEN
CALL ERRORS(CRDER_ERR, 1);
DO FOR CP = 2 TO TEXT LIMIT;
IF LIN$CP = '*1 THEN
225 M1 INDICATOR$ICP = 0;
226 M1 ELSE IF TYPE = 0 THEN CC;
237 M1 INDICATOR$ICP = COUNT-INDICATOR$CP +1;
238 M1 END;
239 M1 END;
240 M1 RETURN;
241 M1 END;
242 M1 COUNT = COUNT + 1;
243 M1 END;
244 M1 CLCSF COMP;
   C1
   C1
245 M1 GET_GROUP:
246 M1 PROCEDURE;
247 M1 E_LINE = E_LINES(INDEX TO #) || BLANKS;
248 M1 S_LINE = S_LINES(INDEX TO #) || BLANKS;
249 M1 LAST_E_COUNT = E_COUNT;
250 M1 LAST_S_COUNT = S_COUNT;
251 M1 E_COUNT, S_COUNT = 0;
252 M1 GO TO LOOP;
253 M1 READ_IT;
254 M1 CALL READ_CARD;
255 M1 IF NOT ORDER CK(PREV_CARD) THEN CC;
256 M1 CALL ERRCS(ERRCS_ERR,1);
257 M1 GO TO READ_IT;
258 M1 END;
259 M1 LOOP:
260 M1 IFF END_GROUP THEN GO TO FCUND_GROUP;
HAL COMPILATION -- PHASE 1 -- INTERNETICS, INC.

STMT          SOURCE          LINE          CURRENT SCOPE
258 M1 EN CASE CARD_TYPE(CURRENT_CARDS$1) + 1;
259 M1 DO: /*CASE 1, A DUMMY*/ END;
261 M1 DC: /*CASE 2 E-LINE*/
262 M1 CALL CCMP(0) ASSIGN
263 M1 (E_LINE,F_INDICATOR,F_COUNT);
264 M1 CC TO LOOP;
266 M1 END: /*OF CASE 2*/
268 M1 DC: /*CASE 3 W-LINE*/
269 M1 M_LINE = M_LINE$($INDX TO #) || CURRENT_CARDS$2 TO #);
270 M1 SAVE_CARDS$1 = 'V';
271 M1 PREV_CARD = CURRENT_CARDS$1;
272 M1 GO TO READ_IT;
274 M1 FAC: /*OF CASE 3*/
275 M1 DO: /*CASE 4 S-LINE*/
276 M1 CALL CCMP(1) ASSIGN
277 M1 (S_LINE,S_INDICATOR,S_COUNT);
278 M1 GO TO LOOP;
279 M1 ENC: /*OF CASE 4*/
280 M1 DC: /*OF CASE 5 COMMENT*/
281 M1 PREV_CARD = CURRENT_CARDS$1;
282 M1 CALL PROCESS_COMMENT;
283 M1 GO TO READ_IT;
284 M1 ENC: /*OF CASE 5*/
285 M1 ENC: /*OF DO CASE*/
287 M1 FCND_GROUP;
288 M1 WRITE(6) SKIP(1);
289 M1 END_GROUP = FALSE;
290 M1 F_LINE = E_LINE$1 TO LENGTH(M_LINE));
I N T E R M E T R I C S , S T V T 2846

H.8 5

M' 2 7 ' 4 2 8 , M I 2 9 ; V , 2 o A M 2 0 4

M I 2 9 ; 5 M I 2 6 M I c l c l 2 2 7 v I c l c l 2 c 5 1 . 1 3 0 1 v i

3202 30? 03 I

304 YI 3Cc 1.1

I

source

LINE CURRENT SCOPE

284 M I IF E_COUNT NOT > 0, THEN DC;
285 M I DC FOR CP = 2 TO TEXT_LIMIT;
286 M I E INDICATOR&CP = 0;
287 M I END;
288 M I E_COUNT = LAST_E_COUNT;
289 M I END;
290 M I S LINE = S_LINES(1 TC LENGTH(M LINE));
291 M I IF S_COUNT NOT > 0 THEN DC;
292 M I DC FOR CP = 2 TO TEXT_LIMIT;
293 M I S_INDICATOR&CP = 0;
294 M I END;
295 M I S_COUNT = LAST_S_COUNT;
296 M I END;

C I THE FOLLOWING STATEMENTS ARE FOR DEBUGGING PURPOSES ONLY
C I OUT 'E_LINE""∥ E LINE∥ """";
C I OUT 'M LINE""∥ M LINE∥ """";
C I OUT 'S_LINE""∥ S LINE∥ """";
297 M I CLOSE GET_GROUP;

C I

C I

298 M I PROCEDURE;
299 M I INDX = INDX + 1;
300 M I IF INDX = TEXT_LIMIT THEN CO;
C I OUT OF DATA, GET MORE.
C I

298 M I PROCEDURE:
299 M I INDX = INDX + 1;
300 M I IF INDX = TEXT_LIMIT THEN CO;
C I OUT OF DATA, GET MORE.
HAL COMPILATION -- PHASE 1 -- INTERMETRICS, INC.

STM | SOURCE | LINE | CURRENT SCOPE
--- | --- | --- | ---
305 | CLCSE CHCP; | 441 | STREAM
306 | # | 442 | STREAM
307 | # | 443 | STREAM
307 | STACK: | 444 | STREAM
309 | PROCEDURE (TYPE, INDICATOR, LIN) ASSIGN (IND, STACK, PP); | 445 | STACK
309 | DECLARE INTEGER, TYPE, PP; | 446 | STACK
309 | DECLARE CHARACTER(*), LIN, STACK; | 447 | STACK
310 | DECLARE ARRAY(256) INTEGER, INDICATOR, IND; | 448 | STACK
311 | IF PP < 1 THEN GOTO NOT_MULTIPLE; | 449 | STACK
312 | IF LIN$INDX = * THEN DO; | 450 | STACK
313 | IF STACK$PP = * THEN | 451 | STACK
313 | IND$PP = IND$PP +1; | 452 | STACK
314 | ELSE GOTO NOT_MULTIPLE; | 453 | STACK
315 | END; | 454 | STACK
316 | ELSE DO; | 455 | STACK
317 | NOT_MULTIPLE: | 456 | STACK
317 | PP = PP +1; | 457 | STACK
318 | IF PP > 255 THEN GOTO CASE TYPE+1; | 458 | STACK
319 | CALL ERROR$('EXPONENT STRING OVER FLOW', 3); | 459 | STACK CASE 1
320 | CALL ERROR$('SUBSCRIPT STRING OVER FLOW', 3); | 460 | STACK CASE 2
321 | END; /* CF DO CASE */ | 461 | STACK CASE 3
322 | STACK = STACK || LIN$INDX; | 462 | STACK CASE 4
323 | IND$PP = INDICATOR$INDX; | 463 | STACK
324 | END; | 464 | STACK
325 | CLOSE STACK; | 465 | STREAM
326 | BUILD_XSCRIPTS; | 466 | STREAM
326 | | 467 | STREAM
326 | | 468 | STREAM
326 | | 469 | STREAM
INSTRUCTIONS

326 M1 PROCEDURE;
327 M1 E_STACK, S_STACK = ' ';
328 M1 E_BLANKS, S_BLANKS = -1;
329 M1 EP, SP = 0;
330 M1 CHECK_M:
331 M1 IF M_LINES$INDEX = ' ' THEN
332 M1 PROCESS;
333 M1 DO;
334 M1 CALL STACK(0, E_INDICATOR, E_LINE) ASSIGN
335 M1 (E_INC, E_STACK, EP);
336 M1 CALL STACK(1, S_INDICATOR, S_LINE) ASSIGN
337 M1 (S_INC, S_STACK, SP);
338 M1 CALL CHOP;
339 M1 GO TO CHECK_M;
340 M1 END;
341 M1 ELSE /* A NON BLANK ON S-LIN*/
342 M1 DC;
343 M1 IF MCOMMENT THEN DC;
344 M1 IF M_LINES$INDEX = '#' THEN
345 M1 M.Comment = FALSE;
346 M1 M_LINES$(INDEX +1) = ' ';
347 M1 END;
348 M1 GO TO PROCESS;
349 M1 END;
350 M1 IF M_LINES$INDEX = '/ ' THEN
351 M1 M_LINES$(INDEX +1) = ' ';
352 M1 M.Comment = TRUE;
353 M1 M_LINES$(INDEX +1) = ' ';
354 M1 GO TO PROCESS;
355 M1 END.

STMT 
SOURCE
LINE CURRENT SCOPE

244 M1 M_LINE1(DHX +1) = " ";
498 BUILD_XSCRIPTS

247 M1 GC TO PROCESS:
499 BUILD_XSCRIPTS

248 M1 END;
500 BUILD_XSCRIPTS

249 M1 IF S_STACK$SP = " " THEN DO;
501 BUILD_XSCRIPTS

250 M1 IF SP > 1 THEN S_STACK = S_STACK$1 TO SP-1);
502 BUILD_XSCRIPTS

251 M1 ELSE S_STACK = " ";
503 BUILD_XSCRIPTS

252 M1 S_BLANKS = S_IND$SP;
504 BUILD_XSCRIPTS

253 M1 END;
505 BUILD_XSCRIPTS

254 M1 IF E_STACK$SP = " " THEN DO;
506 BUILD_XSCRIPTS

255 M1 IF EP > 1 THEN E_STACK = E_STACK$1 TO EP-1);
507 BUILD_XSCRIPTS

256 M1 ELSE E_STACK = " ";
508 BUILD_XSCRIPTS

257 M1 E_BLANKS = E_IND$EP;
509 BUILD_XSCRIPTS

258 M1 END;
510 BUILD_XSCRIPTS

259 M1 IF E_BLANKS >= S_BLANKS THEN
511 BUILD_XSCRIPTS

260 M1 M_BLANKS = S_BLANKS;
512 BUILD_XSCRIPTS

261 M1 ELSE M_BLANKS = E_BLANKS;
513 BUILD_XSCRIPTS

262 M1 END;
514 BUILD_XSCRIPTS

THE FOLLOWING STATEMENTS ARE FOR DEBUGGING PURPOSES ONLY
515 BUILD_XSCRIPTS

OUT "$E_STACK=" $E_STACK $E_STACK$"
516 BUILD_XSCRIPTS

OUT "$S_STACK=" $S_STACK $S_STACK$"
517 BUILD_XSCRIPTS

262 M1 CLOSE BUILD_XSCRIPTS;
518 STREAM

STREAM START:
519 STREAM

263 M1 IFP FIRST_CALL_TO_STREAM THEN DC;
520 STREAM

264 M1 TIME1 = TIME;
521 STREAM

265 M1 FIRST_CALL_TO_STREAM = FALSE;
522 STREAM

266 M1 AGAIN:
523 STREAM

266 M1 CALL READ_CARD;
524 STREAM

PAGE 18
247 | IF NOT CRDEP_CK('C') THEN GO;
248 | CALL ERRORS(CRDEP_ERR,1);
249 | GO TO AGAIN;
250 | FAC;
251 | TEXT_LIMIT = LENGTH(CURRENT_CARD);
252 | RETURNING_M = TRLF;
253 | N_LINE, E_LINE, S_LINE = ' ';
254 | INDX = 1;
255 | CALL GET_GROUP;
256 | DISTANCE = -1;
257 | END = 2;
258 | N = 1;
259 | ENC;
260 | IFF MACRO_FOUND THEN DC;
261 | IF MACRO_POINT < MACRO_LIMIT THEN DO;
262 | NEXT_CHAR = MACRO_STREAM$MACRO_POINT;
263 | MACRO_POINT = MACRO_POINT +1;
264 | RETURN;
265 | ENC;
266 | IF SAVE_BLANK_COUNT >= 0 THEN DC;
267 | NEXT_CHAR = ' ';
268 | BLANK_COUNT = SAVE_BLANK_COUNT;
269 | SAVE_BLANK_COUNT = -1;
270 | RETURN;
271 | ENC;
272 | MACRO_FOUND = FALSE;
273 | NEXT_CHAR = SAVE_NEXT_CHAR;
STMT: SOURCE

394 1 OVER_PUNCH = SAVE_OVER_PUNCH;
395 1 MACRO_STREAM = "";
396 1 RETURN;
397 1 FAR:
398 1 BLANK_COUNT = -1;
399 1 STACK_CHECK:
400 1 DC FOR II = 11 TO 3;/CHECK LIMIT*/
400 1 IF RETURN_CHAR NOT = 0 THEN DO;
401 1 ARROW_FLAG = TRUF;
402 1 RETURN_CHAR = RETURN_CHAR -1;
403 1 NEXT_CHAR = TYPE_CHAR ;
404 1 OVER_PUNCH =0;
405 1 RETURN;
406 1 END;
407 1 END;
408 1 IT = 1;
409 1 IFF ARROW_FLAG THEN DC;
410 1 ARROW_FLAG = .FALSE.:
411 1 NEXT_CHAR = SAVE_NEXT_CHAR;
412 1 OVER_PUNCH = SAVE_OVER_PUNCH;
413 1 BLANK_COUNT = SAVE_BLANK_COUNT;
414 1 RETURN;
415 1 END;
416 1 BEGINING:
417 1 IFF RETURNING_\^ THEN DC:
418 1 IFF M_BLANKS >= 0 THEN DO;
419 1

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<th>LINE</th>
<th>CURRENT SCOPE</th>
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<tr>
<td>418 M1</td>
<td>NEXT_CHAP = ' ';</td>
<td>584</td>
<td>STREAM</td>
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<tr>
<td>419 M1</td>
<td>ARROW = LAST_E_IND;</td>
<td>585</td>
<td>STREAM</td>
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<tr>
<td>420 M1</td>
<td>LAST_E_IND = 0;</td>
<td>586</td>
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<tr>
<td>421 M1</td>
<td>FLANK_COUNT = _BLANKS;</td>
<td>587</td>
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<tr>
<td>422 M1</td>
<td>_BLANKS = -1;</td>
<td>588</td>
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<tr>
<td>423 M1</td>
<td>GO TO FIRST_CHAR;</td>
<td>589</td>
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<td>424 M1</td>
<td>FAC;</td>
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<tr>
<td>425 M1</td>
<td>IF _LINES_INDEX NOT = '&quot;' THEN DO;</td>
<td>591</td>
<td>STREAM</td>
</tr>
<tr>
<td>426 M1</td>
<td>IF _LINES_INDEX = '/' THEN</td>
<td>592</td>
<td>STREAM</td>
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<tr>
<td>427 M1</td>
<td>IF _LINES_INDEX (+1) = '&quot;' THEN DO;</td>
<td>593</td>
<td>STREAM</td>
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<tr>
<td>428 M1</td>
<td>HERE IS A START OF A COMMENT</td>
<td>594</td>
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<tr>
<td>429 M1</td>
<td>_COMMENT = TRUE;</td>
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<td>430 M1</td>
<td>_LINES_INDEX = ' ';</td>
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<tr>
<td>431 M1</td>
<td>_LINES_INDEX (+1) = ' ';</td>
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<tr>
<td>432 M1</td>
<td>GO TO BLANK;</td>
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<td>433 M1</td>
<td>FAC;</td>
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<td>434 M1</td>
<td>IF E_COUNT &gt; 0 THEN DO;</td>
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<td>435 M1</td>
<td>IF E_LINES_INDEX NOT = '&quot;' THEN DO;</td>
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<tr>
<td>436 M1</td>
<td>IF _INICATORE_INDEX NOT = 1 THEN</td>
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<tr>
<td>437 M1</td>
<td>CALL_ERRORS('E-LINE OVERLAPS _LINES',1);</td>
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<td>STREAM</td>
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<tr>
<td>438 M1</td>
<td>ELSE OVER_PUNCH = _LINES_INDEX;</td>
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<td>439 M1</td>
<td>ENC;</td>
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<td>440 M1</td>
<td>ELSE OVER_PUNCH = 0;</td>
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<td>441 M1</td>
<td>END;</td>
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<td>442 M1</td>
<td>ELSE OVER_PUNCH = 0;</td>
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<td>443 M1</td>
<td>IF S_COUNT &gt; 0 THEN</td>
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<tr>
<td>444 M1</td>
<td>IF S_LINES_INDEX NOT = '&quot;' THEN</td>
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<tr>
<td>445 M1</td>
<td>CALL_ERRORS('S-LINE OVERLAPS _LINES',1);</td>
<td>611</td>
<td>STREAM</td>
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</table>
STMT

441 M1 ARROW = LAST_E_IND;
442 M1 LAST_E_IND = C;
443 M1 NEXT_CHAR = M_LINE$INDEX;
444 M1 CALL CHCP;
445 M1 GC TO FFOUND_CHAR;
446 M1 ENC;
447 M1 ELSE
447 M1 PLANK:
447 M1 DO:
448 M1 CALL BUILD_XSCRIPTS;
449 M1 EVER_PUNCH = 0;
450 M1 RETURNING_M = FALSE;
451 M1 LAST_S_IND = 0;
452 M1 RETURNING_S = TRUE;
453 M1 PCINTER = 1; /*THIS CNE MAY NOT BE NEEDED*/
454 M1 ENC;
455 M1 END;
456 M1 IFF RETURNING_S THEN DC;
457 M1 IF LENGTH(S_STACK) > 0 
457 M1 PCINTER <= LENGTH(S_STACK) THEN DC;
458 M1 IF S_STACK$PCINTER = ' ' THEN DC;
459 M1 IF S_INDEX$PCINTER >= 0 THEN
460 M1 DC;
461 M1 NEXT_CHAR = ' ';
461 M1 BLANK_COUNT = S_INDEX$PCINTER;
462 M1 FCINTER = POINTER + 1;
463 M1 ARROW = LAST_S_IND - S_INDEX$PCINTER;
LAST_S_IND = S_INDEX_POINTER;
ENC;
END;
FLSE DC; /* A NON BLANK*/
NEXT_CHAR = S_STACK_POINTER;
ARROW = LAST_S_IND - S_INDEX_POINTER;
LAST_S_IND = S_INDEX_POINTER;
POINTER = POINTER + 1;
END;
GO TO FOUND_CHAR;
END;
FLSE DC; /* CAN NOT RETURN*/
RETURNING_S = FALSE;
RETURNING_E = TRUE;
LAST_E_IND = LAST_S_IND;
POINTER = 1;
END;
IFF RETURNING_E THEN DC;
IF LENGTH(E_STACK) > 0 &
PINTER <= LENGTH(E_STACK) THEN DC;
IF E_STACK$POINTER = ' ' THEN DO;
IF E_INDEX$POINTER >= 0 THEN
MORE TO GO.
DC;
NEXT_CHAR = ' ';
BLANK_COUNT = E_INDEX$POINTER;
POINTER = POINTER + 1;
HAL Compilation -- Phase 1 -- Intermetrics, Inc.

```
STMT  SOURCE   LINE CURRENT SCOPE
489 M  ARROW = E_IND$POINTER - LAST_E_IND;
490 M  LAST_E_IND = E_IND$POINTER;
491 M  END;
492 M  END;
493 M  ELSE
494 M  CI A NON BLANK
497 M  DO:
494 M  NEXT_CHAR = E_STACK$POINTER;
495 M  ARROW = E_IND$POINTER - LAST_E_IND;
496 M  LAST_E_IND = E_IND$POINTER;
497 M  POINTER = POINTER + 1;
498 M  END;
499 M  GC TO FOUND_CHAR;
500 M  FND;
501 M  ELSE
502 M  CI CAN NOT RETURN
501 M  DO:
502 M  RETURNING_E = FALSE;
502 M  RETURNING_M = TRUE;
503 M  FND;
504 M  FND;
505 M  FND;
506 M  GO TO BEGINING;
507 M  FOUND_CHAR;
507 M  IF ARROW NOT = 0 THEN DC;
508 M  OLD_LEVEL = NEW_LEVEL;
509 M  NEW_LEVEL = NEW_LEVEL + ARROW;
510 M  SAVE_OVER_PUNCH = OVER_PUNCH;
511 M  SAVE_NEXT_CHAR = NEXT_CHAR;
```
HAL COMPILATION -- PHASE 1 -- INTERMETRICS, INC.

STMT | SOURCE | LINE | CURRENT | SCOPE
--- | --- | --- | --- | ---
512 M1 | SAVE_BLANK_COUNT = BLANK_COUNT; | 696 | STREAM |
513 M1 | IF OLD_LEVEL > 0 THEN DC; | 697 | STREAM |
514 M1 | IF ARROW < 0 THEN CALL STACK_RETURN_CHAR(ARROW,'*'); | 698 | STREAM |
515 M1 | ELSE | 699 | STREAM |
516 M1 | EXPONENT: | 700 | STREAM |
517 M1 | DU; | 701 | STREAM |
518 M1 | IF ARROW > 1 THEN CALL ERRORS(LINE_ERR,1); | 702 | STREAM |
519 M1 | CALL STACK_RETURN_CHAR(2,'**'); | 703 | STREAM |
520 M1 | CALL STACK_RETURN_CHAR(ARROW,'('); | 704 | STREAM |
521 M1 | END; | 705 | STREAM |
522 M1 | END; | 706 | STREAM |
523 M1 | ELSE IF OLD_LEVEL = 0 THEN DO; | 707 | STREAM |
524 M1 | IF ARROW < 0 THEN CALL STACK_RETURN_CHAR(ARROW,'*'); | 708 | STREAM |
525 M1 | CALL STACK_RETURN_CHAR(ARROW,'('); | 709 | STREAM |
526 M1 | END; | 710 | STREAM |
527 M1 | ELSE GC TO EXPONENT; | 711 | STREAM |
528 M1 | END; | 712 | STREAM |
529 M1 | ELSE if OLD < 0 then GO; | 713 | STREAM |
530 M1 | IF ARROW < 0 THEN GO TO SUBS; | 714 | STREAM |
531 M1 | IF NEW_LEVEL <= 0 THEN CALL STACK_RETURN_CHAR(ARROW,'*'); | 715 | STREAM |
<table>
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<tr>
<th>STMT</th>
<th>SOURCE</th>
<th>LINE</th>
<th>CURRENT SCOPE</th>
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<tr>
<td>537 M1</td>
<td>ELSE DC;</td>
<td>724</td>
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<tr>
<td>538 M1</td>
<td>CALL STACK_RETURN_CHAR(-CLC_LEVEL,'*');</td>
<td>725</td>
<td>STREAM</td>
</tr>
<tr>
<td>539 M1</td>
<td>IF NEW_LEVEL &gt; 1 THEN CALL ERRORS(E_LINE_ERR,1);</td>
<td>726</td>
<td>STREAM</td>
</tr>
<tr>
<td>540 M1</td>
<td>CALL STACK_RETURN_CHAR(2,'*');</td>
<td>727</td>
<td>STREAM</td>
</tr>
<tr>
<td>541 M1</td>
<td>CALL STACK_RETURN_CHAR(NEW_LEVEL,'*');</td>
<td>728</td>
<td>STREAM</td>
</tr>
<tr>
<td>542 M1</td>
<td>END;</td>
<td>729</td>
<td>STREAM</td>
</tr>
<tr>
<td>543 M1</td>
<td>END;</td>
<td>730</td>
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<tr>
<td>544 M1</td>
<td>ARROW = 0;</td>
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<tr>
<td>545 M1</td>
<td>GO TO STACK_CHECK;</td>
<td>732</td>
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<td>546 M1</td>
<td>END;</td>
<td>733</td>
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<tr>
<td>547 M1</td>
<td>RETURN;</td>
<td>734</td>
<td>STREAM</td>
</tr>
<tr>
<td>548 M1</td>
<td>CLOSE STREAM;</td>
<td>735</td>
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<tr>
<td>549 M1</td>
<td>PROGRAM TO TEST THE STREAM PROCEDURE</td>
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<td>550 M1</td>
<td>MAIN_PROGRAM:</td>
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<tr>
<td>551 M1</td>
<td>WRITE(6) 'BEGIN TEST OF HAL IN HAL';</td>
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<tr>
<td>552 M1</td>
<td>BUILT, BUILT_UP, BUILT_TOKEN, BUILT_C_P='';</td>
<td>739</td>
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</tr>
<tr>
<td>553 M1</td>
<td>MAIN_LOOP: DC FCREVER;</td>
<td>740</td>
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</tr>
<tr>
<td>554 M1</td>
<td>CALL STREAM;</td>
<td>741</td>
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</tr>
<tr>
<td>555 M1</td>
<td>IF NEXT_CHAR = '' THEN DC;</td>
<td>742</td>
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<tr>
<td>556 M1</td>
<td>IFF BLANK_FLAG THEN GO TO MAIN_LOOP;</td>
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<tr>
<td>557 M1</td>
<td>ELSE BLANK_FLAG = TRUF;</td>
<td>744</td>
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<tr>
<td>558 M1</td>
<td>END;</td>
<td>745</td>
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<tr>
<td>559 M1</td>
<td>ELSE BLANK_FLAG = FALSE;</td>
<td>746</td>
<td>HALINHAL</td>
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<tr>
<td>560 M1</td>
<td>BUILT = BUILT</td>
<td></td>
<td>NEXT_CHAR;</td>
</tr>
<tr>
<td>561 M1</td>
<td>IF CVER_PUNCH = '0' THEN DC;</td>
<td>748</td>
<td>HALINHAL</td>
</tr>
</tbody>
</table>

**PAGE 26**
HAL C COMPILATION -- PHASE 1 -- INTERMETRICS, INC.

STM

555 M] BUILT_UP = BUILT_UP || ' ';
556 M] END;
557 M] ELSE DC;
558 M] BUILT_UP = BUILT_UP || OVRPUNCH;
559 M] END;
560 M] IF NEXT_CHAR NOT < 'A' THEN DO;
561 M] BUILT_TOKEN = BUILT_TOKEN || NEXT_CHAR;
562 M] IF OVRPUNCH NOT = 'O' THEN BUILT_O_P = OVRPUNCH;
563 M] END;
564 M] ELSE DC;
565 M] IF LENGTH(BUILD_TOKEN) NOT = 0 THEN DD;
566 M] IF BUILT_O_P = '.' THEN WRITE(6) '***TOKEN=' || BUILT_TOKEN;
567 M] ELSE WRITE(6) '***TOKEN=' || BUILT_TOKEN || ',MARKER=' || BUILT_O_P;
568 M] BUILT_TOKEN, BUILT_C_P = ' ';
569 M] END;
570 M] IF NEXT_CHAR NOT = ' ' THEN WRITE(6) '***TOKEN=' || NEXT_CHAR;
571 M] ELSE WRITE(6) '***BLANKS=' || BLANK_COUNT + 1;
572 M] END;
573 M] IF NEXT_CHAR = ':' THEN DD;
574 M] WRITE(6) SKIP(?), '***CVEP***' || BUILT_UP;
575 M] WRITE(6) '***MAIN***' || BUILT, SKIP(?);
576 M] BUILT, BUILT_UP = ' ';
577 M] END;
578 M] IF NEXT_CHAR = '?' THEN GO TO DISASTER;
579 M] END: /* DO FOREVER */
580 M] DISASTER:
540  CALL PRINT_SUMMARY;
581  WRITE(6) 'THIS TEST IS NOW COMPLETE.';
582  CLOSE HALINHAL;
   A B C D E
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The table above shows the flags and statement numbers for the HAL compilation -- Phase 1 -- Intermetrics, Inc. project. The flag key is as follows: 4 = Assignment, 2 = Reference, 1 = Subscript Use.
MACRO TEXT LISTING:

LCC TEXT

1 REPLACE
2 0
3 1
4 INTEGER
5 IF C =
6 IF 1 =
7 WRITE(6)
8 WHILE 1 = 1

STACKING DECISIONS = 13442
CALLS TO SCAN = 3676
CALLS TO IDENTIFY = 9727
NUMBER OF PREDICIONS = 9727
MAX STACK SIZE = 25
MAX IND. STACK SIZE = 32
END IND. STACK SIZE = 17
MAX EXT ARRAY INDEX = 2
XREF LIST PAGINATES = 870
STATEMENT COUNT = 979
MAX CUTTF LIST INDEX = 0
MAX NESTING DEPTH = 3
FREE STRING AREA = F5355

786 CARDS WERE PROCESSED.
NO ERRORS WERE DETECTED DURING PHASE 1.

TOTAL ELAPSED TIME IN COMPILER 0:0:20.52.
ELAPSED SET UP TIME 0:0:0.04.
ACTUAL ELAPSED COMPILING TIME 0:0:14.33.
ELAPSED CLEAR-UP TIME AT END 0:0:11.35.
PROCESSING RATE: 2465 CARES PER MINUTE.
BEGIN TEST CF PAL IN HAL

1 CL 2 5 6
2 M1 PARM:PROGRAM:

**DECLARKS=1
**DECLARKS=1
**DECLARKS=1
**DECLARKS=1
**DECLARKS=1

3 M1 DECLARE M1 ;
+ S1 ; 3,3

**DECLARKS=45
**DECLARKS=45

4 M1 DECLARE M1 ;

5 M1 DECLARE M1 ;

6 M1 =
7 M1 M2 ;
8 S1 ; 8,8
37

**DECLARKS=4
**DECLARKS=4
**DECLARKS=2
**DECLARKS=2

9 M1 DECLARE II ARRAY(S) INTEGER INITIAL(2, 2, 5, 4, 1);
**BLANKS=1
**TCKFN=INTEGER
**BLANKS=1
**TCKFN=INITIAL
**TOKFN=1
**TCKFN=3
**TOKFN=2
**TOKFN=6
**TOKFN=4
**TOKFN=1
**TOKFN=1

***DEFDE***
***MA***
*** DECLARE II ARRAY(5) INTEGER INITIAL(3,2,5,4,1):***

10 **DECLARE ARRAY(5) SCALAR, S1, S2:**

**BLANKS=32
**TCKFN=DECLARE
**BLANKS=1
**TCKFN=ARRAY
**TOKFN={
**TOKFN=5
**TOKFN=}
**BLANKS=1
**TOKFN=SCALAR
**TOKFN=*
**BLANKS=2
**TOKFN=S1
**BLANKS=1
**TOKFN=*
**BLANKS=1
**TOKFN=S2
**TOKFN=:**

***C***
*** *** MAIN ***
*** DECLARE ARRAY(5) SCALAR, S1, S2:
FUNCTION DECLARATIONS
11 ENTER FUNCTION DECLARATIONS
12 END
13 PRO: FUNCTION (P, MATRIX (*,*,):)
14 END

**BLANKS=A7
***TOKEN=PRC1
***TOKEN:
***BLANKS=A
***TOKEN=FUNCTION
**BLANKS=A
***TOKEN=:
***TOKEN=P, MARKER=*.
***TOKEN=*.
***TOKEN=:
***TOKEN=
***TOKEN:
***TOKEN:
***TOKEN:
***TOKEN:
***TOKEN:
***OVER
***MAIN PRO: FUNCTION (P; (*, *)) MATRIX (*, *,):

15 E
16 RETURN P:

**BLANKS=A5
***TOKEN=RETURN
**BLANKS=A
***TOKEN=P, MARKER=*.
***TOKEN=*.
***TOKEN=*.
***TOKEN=:
***TOKEN:
***TOKEN:
***TOKEN:

**OVER
***MAIN RETURN P; (-1):

17 CLCSE PRC1;

**BLANKS=A7
***TOKEN=CLCSE

Reproduced from last available copy.
**ELANS=1**
**TCKFA=PP01**
**TCKEN=1**

**MAIN:*** CLOSE PRO1:

19 M1 PRO: FUNCTION (E) MATRIX (e,e):

20 M1 RETURN PRO1(B 1):
21 S1 2 TO 4 +1 TC 3

17 **BLANKS=56**
MAIN PROGRAM
22 M1 MAIN PROGRAM
24 M1 DC FOR I=1 TO 5;

***BLANKS=67
***TKFN=70
***BLANKS=1
***TOKEN=FOR
***BLANKS=1
***TKFN=I
***TKFN=7
***TKFN=I
***BLANKS=1
***TKFN=TO
***BLANKS=1
***TKFN=5
***TKFN=;

***COVER***
***MAIN*** DC FOR I=1 TO 5;

25 M1 DC FOR J=1 TO 5;

***BLANKS=63
***TKFN=DC
***BLANKS=1
***TKFN=FOR
***BLANKS=1
***TKFN=J
***TKFN=
***TKFN=1
***BLANKS=1
***TKFN=TO
***BLANKS=1
***TKFN=5
***TKFN=;

***COVER***
***MAIN*** DC FOR J=1 TO 5;

26 EI
27 EI
28 EI
29 EI
30 EI

J
I1S1
S1
J
I

***BLANKS=65
***TKFN=V9
***TKFN=8
***TKFN=1
***TKFN=;
***TKFN=J
***TKFN=
***TKFN=1
***BLANKS=1
THE NEXT GROUP HAS AN OVERLAPPING E-LINE


31 | END;
  
**BLANKS**
**TCKFN**END
**TCKFN**;

**OVERS**: END;

32 | THE NEXT GROUP HAS AN OVERLAPPING E-LINE
  33 | 1 1
  34 | **DPR:** 1 OF SEVERITY 1: OVERLAPPING E-LINE CHARACTERS. **
  35 | 1151
  36 | M? = S1; /* COMPARE ARE BLANKS */
  37 | S1 I I

**BLANKS**
**TCKFN**
**TCKFN**;

21 | *
22 | *
23 | *

Reproduced from best available copy.
**ERROR # 2 OF SEVERITY 1: SCUPCE PROGRAM CUT OF ORDER. LAST ERROR ON LINE 33. ****
29 CI THIS SHOULD DEMONSTRATE CARDS CUT OF ORDER
37 $1 = $ ?
40 $ ! 1

**ERROR # 3 OF SEVERITY 1: S-LINE OVERLAPS M-LINE. LAST ERROR ON LINE 37. ****

**BLANKS=67
**TCKEN=S?
**TCKEN=1
**TCKEN=5
**TCKEN=5
**TCKEN=5
**TCKEN=5
**TCKEN=5
**TCKEN=5
**TCKEN=5
**TCKEN=5
**TCKEN=5

**BLANKS=71
**TCKEN=END
**TCKEN=1

**VARIABLES
**VARIABLES END;

**ERROR # 2
**ERROR # 2

42 M1 END;

**BLANKS=75
**TCKEN=MARKER=
**TCKEN=*
**TCKEN=PRC
**TOKEN=1
**TOKEN=M2 MARKER**
**TOKEN=2
**TOKEN=4
**BLANKS=1
**TCFPN=AT
**BLANKS=1
**TCFN=3
**TCFN=4
**BLANKS=1
**TCFN=AT
**BLANKS=1
**TCFN=5
**TCFN=5
**BLANKS=2
**TCFN=1
**TOKEN=1

**CUTER** *
**M=PRINT(M2$4 AT 3,4 AT 5 )

46 M1 CLOSE TPARM;

**BLANKS=53
**TCFN=CLCSF
**BLANKS=1
**TCFN=TPARM
**TCFN=1

**GVE**
**MAIN** CLOSE TPARM;

47 M1 

**BLANKS=47
**TCFN=2
47 CARDS WERE PROCESSED
3 ERRORS WERE DETECTED, THE LAST ERROR WAS ON LINE 40
****SUMMARY OF DETECTED ERRORS*****
ERROR # 1 ON LINE 33 OF SEVERITY 1.
ERROR # 2 ON LINE 37 OF SEVERITY 1.
3rd ERROR # 2 ON LINE 40 OF SEVERITY 1.
CARC PROCESSING RATE: 4.426555E+02 CARDS PER MINUTE.
CLOCK TIME IS 4361443
THIS TEST IS NOW COMPLETE.
C TPARM PROGRAM;
M DECLARE M1
S     3,3
S     *
S S,3
S DECLARE n ARRAY(5) INTEGER INITIAL(3,2,5,4,1);
M DECLARE ARRAY(5) SCALAR, S1, S2;
H FUNCTION DECLARATIONS
H PRO1: FUNCTION (P) MATRIX (*,*)
S   RETURN P
S   CLOSE PRO1;
H PRO: FUNCTION (B) MATRIX (*,*);
H DECLARE MATRIX (*,*), B;
S   RETURN PRO1(B);
S   2 TO 4,1 TO 3
S 4,0 3,0 0
S 3,0 0
S 0
M MAIN PROGRAM
H DO FOR I=1 TO 5;
H DO FOR J=1 TO 5;
H I1$1
H M2 = S1
S 1,0 11
S END;
H THE NEXT GROUP HAS AN OVERLAPPING E LINE
H S1$1
H S2 = S1 ; /* COMMENTS ARE BLANKS */
S 1,1 2
S 2
S 3,0 2,0 0,0
S THIS SHOULD DEMONSTRATE CARDS OUT OF ORDER
M S2 = S1 ;
S 1,1 1
S CAN S LINE OVERLAP ABOVE
S END;
H *
H M=M2 /* IGNORED */;
S 4 AT 3,4 AT 5
S 4
S CLOSE TPARM;
S ?