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# TAGGED ARITHMETIC

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*Cleveland, Ohio*

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## ABSTRACT

A special tagged arithmetic system has been developed for use with FORTRAN programs written to process experimental data. The tagged arithmetic system carries a condition code with every numerical value and uses a special output to call attention to answers computed by using questionable input data. The questionable input data may result from instrumentation or data recording system malfunctions, which can cause ill-conditioned calculations that result in process-time faults or error conditions.

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## SUMMARY

A special tagged arithmetic system has been developed for use with FORTRAN programs written to process experimental data. The tagged arithmetic system carries a condition code with every numerical value and uses a letter code on the output to call attention to answers computed by using questionable input data. This system eliminates stops from process-time faults or error conditions and permits calculations to be completed with questionable data. It reduces the programing effort formerly required to detect faulty input and thus avoid ill-conditioned calculations. Reprocessing of data is significantly reduced, and the user's confidence in results is increased.

## INTRODUCTION

Most of the experimental data processed at Lewis are digitized quantities of physical measurements recorded by central and remote data recording systems. Since the data are a result of direct measurements, some of the data recorded might lead to impossible operations (e.g., division by zero or the square root of a negative number). For the most part, these data are due to instrument failures or to test point settings where a small error in data causes the calculations to be ill-defined. In many cases, such data can produce plausible, but incorrect, results. Complete error analysis of the source of these faults is impractical to perform internally in the computer while processing the data. Therefore, the calculations must be programed to proceed in the best manner possible, and the questionable data flagged for analysis later. A tagged arithmetic system was designed to aid in the analysis of the experimental data and subsequent calculations performed with the data.

The system was first developed by Mr. L. Richard Turner of Lewis. It was implemented in a special interpretive data processing system in use on the UNIVAC 1103 computer. The present tagged arithmetic system was written for use with FORTRAN IV programs running on the IBM 7094II/704X direct couple systems. It has been in use since the spring of 1966. The system has proved to be extremely useful and thus was also implemented for FORTRAN programs running on the 360/67 with Operating System 360. We know of no other software system or computer designed to carry a condition code along with the data throughout the calculations.

## OVERVIEW OF SYSTEM

The tagged arithmetic system allows processing of data to proceed regardless of the quality of the data. Questionable input data and further calculations based on it are tagged as the data are processed. The appearance of a letter printed immediately to the right of the results on the output alerts the research engineer that his results may be questionable. This letter enables him to analyze the causes of the flag and to make judgment as to the validity of the results. Figure 1 shows sample output from the tagged arithmetic system.

The basis for tagging questionable data consists of one or more of the following elements:

(1) Instrument failure
(2) Digitizer limitations (data exceeding range)
(3) Faulty data syntax
(4) Parity errors
(5) Violation of calibration limits
(6) Programed validity test failure
(7) Impossible arithmetic operation

A word can be tagged at recording time either by the engineer's choice or by the recording hardware (i.e., parity errors). It can be tagged at execution time either by the programer's choice or by the operating system as a result of an impossible arithmetic operation or an operation with a previously tagged word.

The four basic categories of tags are defined as follows

(1) Input tag or engineer's code-out: An input tag must be generated by the data recording systems and/or subprograms which analyze the digitized input of experimental data. This tag is inserted for data which exceed the limit of a digitizer, have parity errors, or have faulty syntax. An engineer can tag data caused by faulty instrumentation by use of the central data recording systems or remotely by use of a plugboard at the site or through communication with the processing programs. Any calculations subsequently based on data with an input tag would also contain the input tag.

(2) Programed validity test failure: This tag is generated by the programer and will take on whatever meaning he desires. It could be used to specify that the number of iterations has exceeded a limit or that a data point has an excessive deviation from a curve fit.

(3) Computer overflow or impossible operation: This tag is reserved for use by the floating-point trap error package which resides in the system. No other source is permitted to insert this tag. The error package (NASA Lewis Research Center 7094II/7044 Direct Couple Monitor Program Reference Manual) in use on the Lewis direct couple computer can establish the existence of the tagged arithmetic system within a particular program and insert tags whenever an impossible operation occurs. For example, the tag might be caused by dividing by zero or taking a square root or logarithm of a negative number.

(4) Calibrations outside a declared range: In processing experimental data an engineer must specify calibrations for the data. A tag is generated whenever a calibrated value falls outside the range for which the calibration has been specified as valid.

The value of tagged arithmetic depends on its proper use by the engineer and programer. When proper precautions have been taken at the recording facility and in the program to insert the necessary tags, data faults will naturally propagate throughout the processing of the data, enabling the engineer to analyze the results of his experiment. The appearance or absence of tags on the printed results gives the engineer an easy clue to the reliability of the processed data.

Tagged arithmetic can be used in other applications. With the exception of the impossible operation, the user can give his own meaning to the categories of tags and use them to trace the effects of specific data or the flow within a program.

## LIMITATIONS

The tagged arithmetic system was designed with the programer, as well as the research engineer, in mind. It was considered undesirable to place restrictions on the programer beyond those that were already part of the operating system; however, a few minor restrictions were found necessary.

### Programing Restrictions

The following restrictions are placed on programs using tagged arithmetic:

(1) Library routines ATAN, ATAN2, GAMMA, ALGAMA, ERF, TANH, TAN, and COTAN must not be referenced for any data that might be tagged. Instead, the entry

names TATAN, TATAN2, TGAMMA, TLGAMA, TERF, TTANH, TTAN, and TCOTAN are provided to handle tagged arguments. All other library routines may be referenced normally.

(2) On large jobs that require overlay, non-FORTRAN library subprograms must be included in the main link.

(3) Output fields for numbers that may be tagged must be large enough to accommodate the alphameric character that represents the tag. In the field specifications Ew.d, Fw.d, and Gw.d both w and d are reduced by 1 to write out a tagged number. In the programer's format specification, d must not be zero.

(4) The load-time debugging package provided by IBM (IBJOB Processor Debugging Package ($IBDBL, *DEBUG, etc.)) may be used if two rules are followed:

(a) Debug requests may only be made at the beginning of a FORTRAN statement. (This is normal for FORTRAN programs.)

(b) Debug requests may not be made on any statement that may result in a subroutine CALL as its first operation (i.e., CALL, READ, WRITE, X = SQRT(X), etc.). Requests may not be made on a CONTINUE statement which immediately precedes the above types of statement.

Tagged numbers printed by debug requests will appear half the magnitude they are and will not be followed by an alphabetic tag since the debug package does not make any special provision to recognize tagged numbers.

(5) The standard method of handling arithmetic errors (NASA Lewis Research Center 7094II/7044 Direct Couple Monitor Program Reference Manual) is slightly altered when using tagged arithmetic. The differences are as follows:

(a) The result of all illegal arithmetic operations, except underflows, will be tagged with a computer overflow or impossible operation tag.

(b) Division by zero will always be treated as an overflow (i.e., the result is set to the largest representable floating-point number). Otherwise, the programer's control of errors is not altered.

(6) FORTRAN logical expressions do not make any provision to handle tagged numbers. An arithmetic expression or variable which is tagged is used in comparisons as follows:

(a) A tagged zero is not equal to zero.

(b) A tagged nonzero is half magnitude.

## Storage Requirements and Timing

Routines of the tagged arithmetic system add less than 1000 words to the storage required for the basic programs. Inclusion of all the optional routines adds less than another 500 words.

A typical data processing job may require twice as much execution time with the tagged arithmetic system. The disadvantage of a longer run time is more than overcome by the advantages of being able to complete a run in spite of questionable data and to evaluate the results with any errors automatically propagated to the resulting output. This reduces the necessity for reprocessing because of questionable data.

## IMPLEMENTATION

The tagged arithmetic system is implemented for use with programs written in FORTRAN IV. Several modifications were made to the operating system to accommodate tagged arithmetic. To further facilitate the scanning and alteration of programs, the system library was ordered to separate routines which need to be scanned from those which do not. These changes in no way affect execution of jobs which do not use the tagged arithmetic system.

### Tagged Format

The sign and characteristic portions of tagged and untagged data words are the same. However, a tagged data word in machine memory is always unnormalized by shifting the mantissa portion one bit position to the right. This gives the tagged data word a unique form.

The four low-order bits of a tagged data word are used to express four categories of faults, as shown in appendix A. Each bit position in the four-bit tag represents a different category of fault. The tag is then the logical OR of the faults which appeared in operands that produced this data word. There are 22 bits to express the significant mantissa, which is considered sufficient for questionable data. Untagged data words suffer no loss of precision. The tagged arithmetic system uses only single-precision (36 bit) floating-point words.

### Instruction Alteration and Recognition

The tagged arithmetic system inserts a mask into every floating-point operation (addition, subtraction, multiplication, and division) and calls to certain mathematical functions. The first octal digit of each of these commands is 0 and is changed to 5. When this changed command is executed, the location of the operation is stored, and control is transferred to a fixed location in the core (i.e., a STORE AND TRAP occurs).

This fixed location then sends control to the arithmetic portion of the tagged arithmetic system. The system removes the mask to recover the original floating-point operation. Control is thus transferred to the system before each floating-point operation to check for the existence of a tagged operand. If there is no tagged operand, the operation is performed normally (after removing the mask). Otherwise, the special tagged arithmetic operations must be used to preserve and propagate the tags, as well as to perform the arithmetic operation specified.

## Tagged Arithmetic Subprograms

The tagged arithmetic system includes 13 subprograms. A description of each of these subprograms is given in appendix B. One subprogram is available to the programer for invoking the tagged arithmetic system. Eight subprograms are available to the programer for examining the tags of numbers, for inserting tags, and for special entries to library routines that would not otherwise be able to handle the tagged numbers. The remaining subprograms are called automatically and do not need to be known by the programer.

The programer must call the subprogram TAGSCN to activate the tagged arithmetic system before executing any other instructions. This subprogram determines the areas of core storage to be scanned for floating-point arithmetic operations. Two areas are scanned, the object program loaded by the programer and all standard library subprograms. TAGSCN calls the SCANTG subprogram, which scans the necessary portion of the core and replaces floating-point operations and certain library subprogram calls so that they will be tested for tagged arithmetic when executed. The replaced operations are addition, subtraction, multiplication, and division, or any of the transfers to the functions SIN, COS, EXP, SQRT, ASQRT, ALOG, and ALOG10.

During execution, the TAGOPE subprogram is entered when an operand is a tagged number. Floating-point arithmetic operations and transfers to the functions SIN, COS, EXP, SQRT, ASQRT, ALOG, and ALOG10 are examined by this subprogram. The tag or tags of the operands are removed, the indicated operation is performed, and the result is flagged with the combined tags of the operands. The subprogram TAGPF is called for the special library routines TATAN, TATAN2, TGAMMA, TLGAMA, and TERF written to replace routines that operate on the characteristic and mantissa of a floating-point argument separately rather than using the standard machine floating-point operations.

## Operating System Modifications

Several modifications were made to the operating system to accommodate the tagged arithmetic system. These in no way affect the execution of jobs which do not use tagged arithmetic. The modifications were as follows:

(1) Reference points were inserted so that information available to the operating system could also be referenced by the tagged arithmetic system.

(2) The standard error package in use at Lewis reports arithmetic errors that cause a machine overflow, underflow, division by zero, or an attempt to use an illegal argument to a standard library arithmetic function The standard error package was modified so that it would insert the appropriate tag into the result of an impossible operation. Error reports are not given if an operand was previously tagged.

(3) Output conversion of floating-point numbers was modified to recognize a tagged number. The conversion normalizes the number and adjusts the field specification to include an alphameric character to represent the appropriate tag.

(4) The routine which overlays links or large jobs was modified to call for a scan of the appropriate area each time a new link is read into the memory. A table of subroutine locations and link numbers is preserved in lower memory by the loader. The loader has been modified to save this table for the Lewis error package.

(5) To further facilitate the scanning and alteration of programs, the system library was reordered to separate routines which need to be scanned from those which do not.

## CONCLUDING REMARKS

A special tagged arithmetic system has been developed at Lewis Research Center for use with FORTRAN programs written to process experimental data. The tagged arithmetic system carries a condition code with every numerical value and uses a letter code on the output to call attention to answers computed using questionable input data.

The programing restrictions for use of the tagged arithmetic system with FORTRAN programs are relatively minor. Considerable programing time is saved by use of the system. The system performs decisions and flags results which otherwise would have to be programed for each experimental test. The disadvantages of the longer run time are more than overcome by the advantages of being able to complete a run in spite of questionable data and to evaluate the results with flags automatically propagated to the resulting output. This reduces the necessity for reprocessing because of questionable data.

The tagged arithmetic system has applications other than processing data which are the results of physical experiments. The bit structure which includes a tag and propagates it through calculations is useful in tracing and general program debugging.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 9, 1969,
129-04-06-03-22.

# APPENDIX A

## BIT STRUCTURES OF TAGGED REAL NUMBERS USED IN FORTRAN PROGRAMS WITH FLOATING ARITHMETIC TRAPS

Let S, E, N, and F represent the sign, exponent, numeric, and fault bits of the real number, respectively. The effect of tagging on the zero and nonzero bit structures can be represented as follows:

| | |
|---|---|
| S 00000000 00000000000000000000000 0 0 0 0 | Untagged zero data |
| S 00000001 00000000000000000000000 $F_8F_4F_2F_1$ | Tagged zero data |
| S EEEEEEEE 1NNNNNNNNNNNNNNNNNNNNNN N N N N | Untagged nonzero data |
| S EEEEEEEE 01NNNNNNNNNNNNNNNNNNNNN $F_8F_4F_2F_1$ | Tagged nonzero data |

The interpretation of the fault bits is as follows:

| | |
|---|---|
| $F_8$ | Input tag or engineer's code-out |
| $F_4$ | Failure of programed test for validity |
| $F_2$ | Computer overflow or impossible operation |
| $F_1$ | Data word outside declared range |

Example:

| | |
|---|---|
| 201400000000 | Octal representation of a floating-point untagged 1 |
| 201200000005 | Floating-point 1 tagged with $F_1$ and $F_4$ bits |

Tagged data output can warn the engineer that a data word is doubtful or faulty. The output of a FORTRAN program using F, E, or G format conversion for real single-precision tagged data words will yield a literal tag appended to the right of the printed result. An example of this output using O16, F16.6, E16.6, and G16.6 on a normal zero, a zero with an input tag, a normal 1, and a 1 with both an input and an out-of-range tag is illustrated as follows:

| Conversion | Untagged zero | Tagged zero | Untagged 1 | Tagged 1 |
|---|---|---|---|---|
| 016 (octal) | 000000000000 | 001000000010 | 201400000000 | 201200000011 |
| F16. 6 | 0 | 0. 00000H | 1. 000000 | 1. 00000S |
| E16. 6 | 0 | 0 00000E-38H | 0. 100000E 01 | 0. 10000E 01S |
| G16. 6 | 0 | 0. 00000E-38H | 1. 000000 | 1. 00000    S |

The tag letters that can appear in the output, such as H and S in the previous illustration, can be interpreted by means of the following key:

| Tag value | Tag meaning | Tag letter | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | S | T | U | V | W | X | Y |
| 8 | Input tag | | | | | | | | * | * | * | * | * | * | * | * |
| 4 | Failure of programed test for validity | | | | * | * | * | * | | | | | * | * | * | * |
| 2 | Impossible operation | | * | * | | | * | * | | | * | * | | | * | * |
| 1 | Out of declared range | * | | * | | * | | * | | * | | * | | * | | * |

# APPENDIX B

## SUBROUTINES USED WITH TAGGED ARITHMETIC

The subroutines used with tagged arithmetic are given in the following table:

| Subroutine | Usage | Call sequence | Error message | Error condition | Optional exit control |
|---|---|---|---|---|---|
| NTAG | Finds tag of tagged number, if any | y = NTAG(x) | None | None | None |
| TAG | Tags a number | CALL TAG(x, n) | *ATTEMPT TO TAG A NONREAL GAVE A TAGGED ZERO | n is not real | $LIBSAR |
| TAGSCN | Sets all floating-point operations for possible tagged arithmetic; determines proper error conditions | CALL TAGSCN | None | None | None |
| UNTAG | Removes tag from tagged number | y = UNTAG(x) | None | None | None |
| TATAN | Calls ATAN for argument that may be tagged | y = TATAN(x) | None | None | None |
| TATAN2 | Calls ATAN2 for argument that may be tagged | y = TATAN2(x, z) | *ILLEGAL ARG. TAGGED ATAN2 | x or z is non-real, nontagged | $LIBSAR |
| TERF | Calls ERF for argument that may be tagged | y = TERF(x) | None | None | None |
| TGAMMA | Calls GAMMA for argument that may be tagged | y = TGAMMA(x) | None | None | None |
| TLGAMA | Calls ALGAMA for argument that may be tagged | y = TLGAMA(x) | None | None | None |
| [a]SCANTG | Changes floating-point operations to tagged operations | None | None | None | None |
| [a]TAGTRP | Tests operands for tagged numbers and performs normal arithmetic operations; sets up output for tagged numbers | None | None | None | None |
| [a]TAGOPE | Performs tagged arithmetic | None | None | None | None |
| [a]TAGPF | Provides linkage to function subprograms for tagged arguments | None | None | None | None |

[a]Used automatically and are not called by the programer.

## Subroutine TAGSCN (Written in MAP)

This subroutine must be called by the program before any other statements are executed in order to use any tagged arithmetic during execution of the program. It determines the areas of core storage to be scanned for possible floating-point arithmetic operations. Two areas will be scanned, the object program loaded by the programer and all standard library subroutines. Three areas are not scanned. These include the resident portion of the IBJOB monitor system itself; nonstandard, non-FORTRAN library routines; and that portion of core storage beyond the loaded object program and library. TAGSCN calls subroutine SCANTG.

## Subroutine SCANTG (Written in FORTRAN IV)

This subroutine actually scans the necessary part of the core and replaces floating-point operations and certain library routine calls so that they may be tested for tagged arithmetic when executed. The first octal digit is set to 5, which will cause (1) the instruction counter to be stored and (2) an illegal operation trap. These operations are addition, subtraction, multiplication, and division, or any of the transfers to the functions SIN, COS, EXP, SQRT, ASQRT, ALOG, and ALOG10.

## Subroutine TAGOPE (Written in FORTRAN IV)

TAGOPE is entered when an operand is a tagged number. The tag or tags of the operands are removed, the indicated operation is performed, and the result is tagged with the combined tags of the operands. Permissible operations are addition, subtraction, multiplication, and division, or one of the functions SIN, COS, EXP, ALOG, SQRT, ASQRT, and ALOG10.

## Subroutine TAGPF (Written in FORTRAN IV)

This logical function will determine if the operand is a tagged number. If it is tagged, a function subprogram will be called to operate on the argument and the function will be set .TRUE.. This function is used by the special library routines that were written to replace routines that operate on the characteristic and mantissa of a floating-point argument separately rather than by using the standard machine floating-point operations.

## Subroutine TAGTRP (Written in MAP)

This subroutine recognizes a command that may be a possible tagged arithmetic operation. If neither operand is tagged, the operation is performed normally. If either one is tagged, TAGOPE is called to perform the operation. This routine also controls the output conversion of tagged numbers in the E or F conversion. If a number to be written out is tagged, the alphabetic tag will appear in the rightmost position of the specified field, thus causing one less significant digit to appear.

## Subroutine NTAG (Written in FORTRAN IV)

This function subprogram is used in a FORTRAN tagged arithmetic data processing job to determine whether a single-precision floating-point number is tagged. An integer is generated, the value of which depends on the fault conditions that apply to the number. The value of that integer is obtained by a reference to NTAG(X). The relations among the value of the integer, the letter used to tag this number in output, and these fault conditions are illustrated as follows:

| Fault conditions that apply to number X | Tag bits of X | Value of NTAG(X) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| | | Tag letter | | | | | | | | | | | | | | |
| | | A | B | C | D | E | F | G | H | S | T | U | V | W | X | Y |
| Input tag or engineer's code-out | 8 | | | | | | | | * | * | * | * | * | * | * | * |
| Failure of programed test for validity | 4 | | | | * | * | * | * | | | | | * | * | * | * |
| Computer overflow or impossible operation | 2 | | * | * | | | * | * | | | * | * | | | * | * |
| Data word outside of declared range | 1 | * | | * | | * | | * | | * | | * | | * | | * |

When X is untagged, NTAG(X) is zero. When X is not a single-precision floating-point number, such as when X is an integer, NTAG(X) is set to the value -31.

## Subroutine TAG (Written in FORTRAN IV)

This subroutine is used to set specified fault bits, called the tag, of a real, single-precision, floating-point data word. The tag is used to specify fault conditions that apply to the data word; the tag NN is defined as follows:

| | |
|---|---|
| NN=8 | input tag or engineer's code-out |
| NN=4 | failure of programed test for validity |
| NN=2 | computer overflow or impossible operation |
| NN=1 | data word has fallen outside declared range |

Tags propagate through tagged arithmetic to the results of the calculation. When E, F, or G format conversions are used for output, the tags are reported as literal tags. Insertion of a tag is made by the statement

CALL TAG(X, N)

where

X data word to be tagged

N fixed-point variable or constant, sum of all values of NN to be inserted with this CALL

Define n congruent to N modulo 16.

(1) When n = 0, X is left unchanged.

(2) When X is untagged, the resulting tag of X is n.

(3) When X is tagged, the resulting tag of X is the logical sum of n and the original tag of X.

(4) An NN=2 in n is ignored. The programer cannot control this bit. The relation among n, the letter tag in the output, and the fault bits is given as follows:

| Tag bit | Value of n | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| | Tag letter | | | | | | | | | | | | | | |
| | A | B | C | D | E | F | G | H | S | T | U | V | W | X | Y |
| NN=8 | | | | | | | | * | * | * | * | * | * | * | * |
| NN=4 | | | | * | * | * | * | | | | | * | * | * | * |
| NN=2 | | * | * | | | * | * | | | * | * | | | * | * |
| NN=1 | * | | * | | * | | * | | * | | * | | * | | * |

When X is nonreal, such as an integer, the following error message is returned by the Execution Error Monitor:

*ATTEMPT TO TAG A NONREAL GAVE A TAGGED ZERO

## Subroutine UNTAG (Written in FORTRAN IV)

This subroutine may be used to remove the tag from a number. If the number has been tagged, the accuracy is limited to the 22 bits available in the mantissa. The statement

Y = UNTAG(X)

stores the untagged value of X in Y. Programers are cautioned about the use of this routine so that the purpose of tagged arithmetic is not wasted.

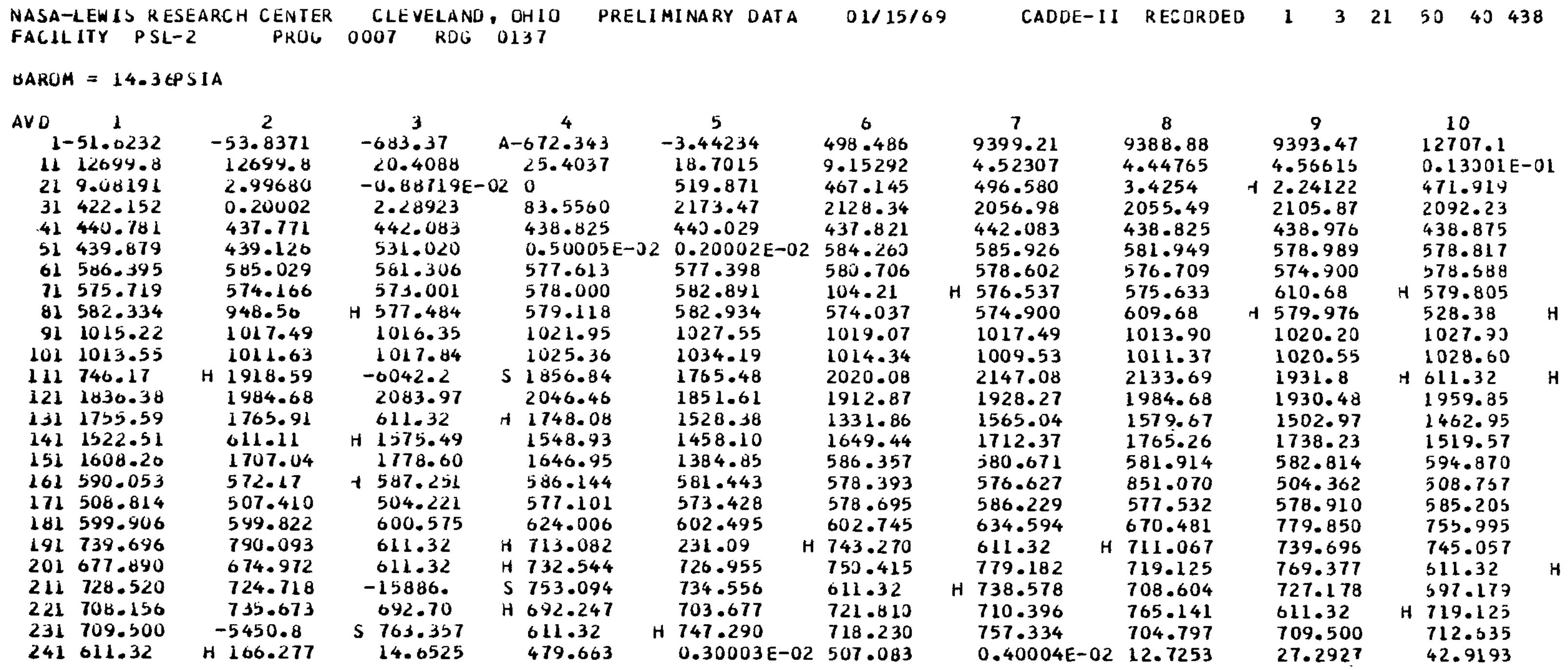
## Subroutines TATAN, TATAN2, TGAMMA, TLGAMA, and TERF (Written in FORTRAN IV)

These function names are used to reference the respective functions whenever there is a possibility that an argument may be a tagged number. These names should always be used by a program that uses tagged arithmetic.

| Use | Do not use |
|---|---|
| z = TATAN(x) | z = ATAN(x) |
| z = TATAN2(x, y) | z = ATAN2(x, y) |
| z = TGAMMA(x) | z = GAMMA(x) |
| z = TLGAMA(x) | z = ALGAMA(x) |
| z = TERF(x) | z = ERF(x) |

Each of these routines calls TAGPF. An entry into the normal library routine is then effected with an untagged argument. If any tag is present, it will be propagated in the function value before return to the user's program.

Figure 1



```
NASA-LEWIS RESEARCH CENTER   CLEVELAND, OHIO   PRELIMINARY DATA    01/15/69      CADDE-II  RECORDED   1   3  21  50  40 438
FACILITY  PSL-2       PROG  0007   RDG  0137

BAROM = 14.36PSIA

AVD     1            2            3            4            5            6            7            8            9           10
  1-51.6232      -53.8371     -683.37     A-672.343    -3.44234      498.486      9399.21      9388.88      9393.47      12707.1
 11 12699.8      12699.8       20.4088     25.4037      18.7015      9.15292      4.52307      4.44765      4.56615      0.13001E-01
 21 9.08191      2.99680     -0.88719E-02 0             519.871      467.145      496.580      3.4254     H 2.24122      471.919
 31 422.152      0.20002       2.28923     83.5560      2173.47      2128.34      2056.98      2055.49      2105.87      2092.23
 41 440.781      437.771       442.083     438.825      440.029      437.821      442.083      438.825      438.976      438.875
 51 439.879      439.126       531.020     0.50005E-02 0.20002E-02 584.260      585.926      581.949      578.989      578.817
 61 586.395      585.029       581.306     577.613      577.398      580.706      578.602      576.709      574.900      578.688
 71 575.719      574.166       573.001     578.000      582.891      104.21     H 576.537      575.633      610.68     H 579.805
 81 582.334      948.56     H 577.484      579.118      582.934      574.037      574.900      609.68     H 579.976      528.38     H
 91 1015.22      1017.49       1016.35     1021.95      1027.55      1019.07      1017.49      1013.90      1020.20      1027.90
101 1013.55      1011.63       1017.84     1025.36      1034.19      1014.34      1009.53      1011.37      1020.55      1028.60
111 746.17     H 1918.59      -6042.2    S 1856.84      1765.48      2020.08      2147.08      2133.69      1931.8     H 611.32     H
121 1836.38      1984.68       2083.97     2046.46      1851.61      1912.87      1928.27      1984.68      1930.48      1959.85
131 1755.59      1765.91       611.32    H 1748.08      1528.38      1331.86      1565.04      1579.67      1502.97      1462.95
141 1522.51      611.11     H 1575.49      1548.93      1458.10      1649.44      1712.37      1765.26      1738.23      1519.57
151 1608.26      1707.04       1778.60     1646.95      1384.85      586.357      580.671      581.914      582.814      594.870
161 590.053      572.17     H 587.251      586.144      581.443      578.393      576.627      851.070      504.362      508.767
171 508.814      507.410       504.221     577.101      573.428      578.695      586.229      577.532      578.910      585.205
181 599.906      599.822       600.575     624.006      602.495      602.745      634.594      670.481      779.850      755.995
191 739.696      790.093       611.32    H 713.082      231.09     H 743.270      611.32     H 711.067      739.696      745.057
201 677.890      674.972       611.32    H 732.544      726.955      750.415      779.182      719.125      769.377      611.32     H
211 728.520      724.718      -15886.    S 753.094      734.556      611.32     H 738.578      708.604      727.178      597.179
221 708.156      735.673       692.70    H 692.247      703.677      721.810      710.396      765.141      611.32     H 719.125
231 709.500     -5450.8     S 763.357      611.32     H 747.290      718.230      757.334      704.797      709.500      712.635
241 611.32     H 166.277       14.6525     479.663     0.30003E-02 507.083      0.40004E-02 12.7253      27.2927      42.9193
```

Figure 1. - Sample output from tagged arithmetic system.

```
DAMPR
  1 0.97992        0.97992      0.97244      0.97992      0.98365      35.7006      35.7044      35.6968      35.7044      35.7006
 11 14.2986        14.2907      14.3026      14.2986      14.3026      0.97917      0.97009      0.98825      0.97917      0.97917
 21 87.7702        87.8156      87.7793      87.7793      87.7793      14.2929      14.2835      14.2835      14.2740      14.2335
 31 0.97300        1.00384      0.97300      0.97300      0.97300      139.856      139.886      139.871      139.856      139.871
 41 14.4107        14.3788      14.3629     -0.3374     A 14.3788      4.85059      4.83111      4.85059      4.85059      4.83890
 51 4.84670        4.36461      4.36073      4.36849      4.37236      4.84280      4.84670      4.81942      4.80383      4.82331
 61 4.83500        4.84280      4.81942      4.79604      4.85059      4.85449      4.82721      4.91298      4.79994      4.84280
 71 4.81552        12.247     H 11.689     H 11.578     H 11.753     H 10.803     H 4.81552      4.7649     H 4.84280      4.80383
 81 4.82331        4.79994      7.1899     H 11.246     H 11.246     H 7.2179     H 11.286     H 4.78825      4.83500      4.82331
 91 4.81162        4.83500      4.81942      4.85059      4.85059      4.2600     H 4.2445     H 4.2638     H 4.2948     H 11.238
101 4.81942        4.83890      4.83111      4.23672      4.28708      4.28708      4.28321      4.28321      4.26771      3.2045
111 3.2314       H 3.2352     H 3.2237     H 4.60923      4.66757      4.72205      4.75709      4.79214      4.83111      4.83500
121 4.56259        4.65590      4.69481      4.72984      4.77656      4.79214      4.80383      4.22123      4.22123      4.22898
131 4.19800        4.21736      10.7388      11.0008      11.0664      11.0196      11.0570      11.141     H 10.9540      10.7763
141 11.0102        11.1132      10.066     H 11.2162      11.5067      11.0102      10.8511      11.4504      11.4129      11.3942
151 11.3099        11.3286      11.4879      10.5986      11.3099      11.1600      11.3192      11.2256      6.7686     H 11.5536
161 10.7295        10.7482      10.8230      10.4210      10.1221      10.8511      10.9072      11.2630      11.0196      9.84211
171 10.9915        11.1319      11.1694      10.7201      9.93541      10.8230      10.9540      13.887     H 11.0289      10.0101
181 10.9260        10.9634      10.9634      10.7108      9.82345      9.42259      8.71527      9.33875      8.62231      9.18044
191 8.58513        11.1881      11.1694      11.1225      8.69667      8.73386      8.52009      7.88886      8.03728      6.99976
201 6.99976        7.55517      10.8792      8.93847      9.52509      8.42718      8.38074      8.43647      8.64090      8.91056
211 9.02221        9.09666      8.46434      8.66879      8.13935      7.83322      8.03728      8.17648      8.38074      61.3882
221 3.2700       H 60.6570      61.5438      61.4971      63.0053      61.0771      60.8748      61.7926      60.6414      61.9537
231 62.8343        61.7149      61.9326      61.5438      62.2592      61.1082      61.5749      61.2794      61.1082      58.7107
241 14.155       H 57.0743      57.1522      13.645     H 55.2647      23.7039      23.6246      23.5928      23.7357      23.4499
251 9.52509        9.53441      9.77682      9.87942      9.55305      10.1501      10.6921      10.9353      10.6360      10.2155
261 10.1688        10.0007      10.2622      10.1314      10.5144      3.1472     H 10.3182      10.0194      10.8230      10.7014

271 10.1127        9.37601      9.32944      9.39464      8.83615      3.73271      9.21769      9.19906      9.24562      9.18044
281 9.42259        9.14321      9.09666      9.41328      9.46918      8.35288      8.78035      8.19504      8.32502      3.21604
291 3.21987        3.22753      3.22753      3.19306      8.89281      8.96997      8.88469      8.81977      8.94559      8.85223
301 8.79949        8.81977      8.84817      8.84817      3.12032      3.24669      3.22753      3.21987      3.21987      3.19306
311 3.20454        3.20454      3.21604      3.21987      3.20454      3.21221      3.22370      8.05583      7.66636      7.66636
321 7.50885        7.28660      7.15703      11.3286      11.6848      11.0570      3.1655     H 11.0570      10.7482      25.1004
331 50.0755        25.4969      28.1910      57.6823      58.7419      60.5481      36.6419      48.5410      30.0746      14.6819
341 14.3629        8.18576      3.23902      3.20071     -0.6268     A-0.6268     A 10971        10951        10898        11031
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Figure 1. - Continued.

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AVERAGES
     PP       2 4.84085       TP      12 439.589       PT1       4 4.84670      PS1       4 4.36655      PT2      32 4.82879
     PS2      6 4.27417       PT2A     3 4.83630       PT2B      5 4.82487      PT2C      5 4.84826      PT2D      3 4.81942
     PT2E    -5 11.614      H PT2F     2 4.82916       PT2G      3 4.80903      PT2H     -5 9.6374     H PT2I      5 4.81864
     PT2J     3 4.84020       PT2K    -5 5.6603      H PT2L      3 4.82981      PTC21     9 4.80989      PTC22     3 4.83630
     PTC23    8 4.83939       PTC25    9 4.82678       PTC26     3 4.85580      PT23     25 11.1548      T23      10 581.768
     PT23A    6 10.9728       PT23B    6 11.1054       PT23C     7 11.3193      PT23D     6 11.1945      PT231C    5 10.7388
     PT232C   5 11.1039       PT233C   5 11.1151       PT234C    4 11.0385      PT235C    5 10.9861      PT236C    3 11.2288
     PT237C   5 11.1826       T23A     5 581.988       T23B      5 581.548      PT2C*    24 10.7033      PS2CI     3 9.31393
     PS2C0    3 8.64090       PS2C10   6 8.97742       T2C      20 577.807      PT2CA     5 10.5687      PT2C8     5 10.7766
     PT2CC    5 10.7897       PT2CD    4 10.7040       PT2CE     5 10.6774      PT2C1     5 10.8642      PT2C2     5 10.9410
     PT2C3    4 11.0547       PT2C4    5 10.7801       PT2C5     5 9.94662      T2CA      5 577.921      T2C3      5 576.755
     T2CC     3 577.325       T2CD     4 580.468       T2CE      3 576.304      T2C1      4 578.199      T2C2      4 576.051
     T2C3     4 575.707       T2C4     4 577.999       T2C5      4 581.079      PT3      19 61.5682      PS3HB     2 57.1132
     PS3TP    1 58.7107       PS3HT    3 57.6457       T3       20 1019.20      PT3A      4 61.2715      PT3B      5 61.4783
     PT3C     5 61.9979       PT3D     5 61.4660       PT31C     4 62.1541      PT32C     3 61.6732      PT33C     4 61.2054
     PT34C    4 61.6371       PT35C    4 61.1976       T3A       5 1019.71      T3B       5 1019.71      T3C       5 1020.52
     T3D      5 1016.68       T31C     4 1015.54       T32C      4 1014.03      T33C      4 1014.87      T34C      4 1022.02
     T35C     4 1029.56       PT51     5 23.6214       T51      20 1907.95      T51A      3 1846.97      T51B      3 2100.28
     T51C     5 1960.62       T51D     5 1943.23       T51E      4 1699.49      T511C     4 1881.23      T512C     5 1948.91
     T513C    3 2067.45       T514C    4 1895.46       T515C     4 1776.33      PT56      5 9.65376      T56      19 1582.00
     T56A     5 1488.50       T56B     4 1526.26       T56C      5 1676.97      T56D      5 1625.14      T561C     4 1528.02
     T562C    3 1661.49       T563C    4 1674.76       T564C     4 1609.27      T565C     4 1456.37      PT25     15 10.3787
     PS25     4 9.23406       T25     11 584.231       PT25A     4 10.6034      PT25B     4 10.1618      PT25C     3 10.3213
     PT25D    4 10.4141       PT251C   4 10.1291       PT252C    4 10.5496      PT253C    3 10.5458      PT254C    4 10.3323
     T25A     4 582.939       T25B     3 590.725       T25C      4 580.652      T251C     3 589.124      T252C     3 584.056
     T253C    2 580.154       T254C    3 582.230       PS0       4 3.20455      PS0S      4 3.21508      NF        3 9393.85
     NC       3 12702.2       FP       2-52.7302       F1        3 2119.60      F2        3 2084.53      F         6 2102.06
     PT2TOP  19 4.83603       PT2BOT   9 4.81595       PT9      20 6.03995
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Figure 1. - Concluded.

*"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."*

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958