# Upgrading HULL Hydrocode for Spherical Airblast Calculations 

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## Introduction

HULL is a complex and versatile hydrodynamic computer code. The original version was developed at the Air Force Weapons Laboratory in 1976 [1]. It has the capability to run Eulerian or Lagrangian modes of calculations and has a wide range of options representing material selection and various physical behavior. One of the drawbacks of HULL is its explicit mode of calculation with a severe time-step limitation. The time-step of calculation, restricted by the Courant, Friedricks and Lewy (CFL) condition, often hampers its efficiency in solving large multidimensional problems. Mere size and complexity of the code adds a certain amount of rigidity in upgrading HULL. It would be ideal if calculations of interest to the Army could be speeded up substantially.

A prior report [2] by the author noted certain anomalies along the centerline of HULL axisymmetric calculations. In the previous study, airblast velocity profiles, pressure plots, and the time of arrival at ground zero, were computed from an airburst detonation. The need for a quicker solution in such an airblast calculation was apparent. The present effort concentrates on upgrading HULL by adding a one-dimensional spherical airblast code, SAP (Spherical Air Puff).

The original SAP code was developed at the Air Force Weapons Laboratory in the 1960 's [3]. However, the version [4] which was used in this study was developed by the $S$-Cubed Corporation in the mid $1980^{\prime} \mathrm{s}$. It has a stand-alone capability of airblast calculations. SAP can also prepare station plots or feed in inputs to HULL or SHARC calculations. Unfortunately, the version that was available to the author lacked several subroutines. The need for complete documentation resulted in redefining several system parameters and options. The program was added to the HULL library in UNICOS and VAX modes. However, thorough testing of SAP against measured airblasts still needs to occur.

This report presents the discussion of the parameters and options in the newly added capability. For brevity, only the important details will be presented here. The executable versions and procedures are given in program listings in the appendix.

## HULL SYSTEM

Before the discussion of SAP begins, it is important to recognize and understand the HULL framework. The HULL system consists of several programs which furnish pre- and post-processing needs in addition to the HULL program, which performs the hydrodynamic calculations. The programs share a common library of utility routines. HULL is very flexible in being able to run on several computer systems and can be upgraded very easily because of its modular structure. HULL is prepared by a proprietary program called SAIL, developed by Shalimar Research, Inc [5]. This code guides the flow of
instructions in the HULL system by using statements, called SAIL directives, which prepare or change the compilable HULL. This is important to recognize because the SAP code which was added to the HULL system would not function itself without being processed by SAIL.

The details of the SAIL program cannot be published because of the proprietary guidelines. It operates under three major modes executive/maintenance, update/generate and copy/convert. The SAIL maintenance and executive directives are its normal mode of operation. However, they cannot be processed simultaneously with the update/generate mode. Once a program is transported between systems using the copy/convert mode, it can be added or upgraded for another installation using proper SAIL directives. Finally, once system parameters and options are defined and available, a program can be executed in the normal mode.

The normal mode of execution is prepared for HULL with the preprocessing programs PLANK and KEEL. The preparation of the compilable HULL is achieved by PLANK, which defines the options block. KEEL utilizes the material library and generates the input/restart tape for hydrodynamic calculations of HULL. Finally, there are post-processing programs such as PULL and STATion to plot the results of hydrodynamic calculations and analyze data.

## SAP Code

SAP is similar to the program HULL. It already contains post-processing programs such as SAPPLT and STAPLT. It was therefore unnecessary to share those programs from the HULL system. Further, SAP does not need the HULL material library "MATLIB", since materials are furnished in several subprograms within SAP which can be compiled upon need. Currently SAP has 24 materials in its library (these include burned and unburned materials). They are - AIR, TNT, BTNT, PBX, BPBX, PENT, BPENT, ANFO, BANFO, METH, BMETH, WATER, HMX, BHMX, COMB, BCOMB, FOAM, CFOUR, BCFOUR, PETN, BPETN, IRMT, BIRMT and PLUG. The material names beginning with the letter "B" represent burned explosives. A continuous burn routine, based upon the Chapman Jouget Theory, is available in SAP.

SAP also has the capability of using six different ambient models. They are: Tropical, Temperate, Arctic, Exponential, Constant Energy and Hiroshima. SAP calculations can incorporate radiation loss. There are three radiation loss schemes - one based upon SPUTTER calculations, one using emissivity data by Gilmer [3], and a radiation-diffusion package with free streaming at the edge of the temperature gradient. SAP uses a real atmosphere that is stable under an $r^{-2}$ gravity field, and an equation of state for air that is an empirical fit to Hilsenrath's data [6].

SAP can be run with a cartesian, cylindrical or spherical system of coordinates. It has two differencing schemes. The original scheme is

Lagrangian, whereas the second scheme, which is also utilized in the HULL code, and can be run as Eulerian or Lagrangian, as set by an option. SAP can incorporate artificial viscosity in linear or quadratic form. It even has a routine for an artificial compression method. The SAP plot routines can furnish overpressures, overdensity, and velocity vectors versus radius. SAP was originally developed for a CDC or CRAY machine under the CTSS mode. Therefore to run under CRAY-UNICOS at WES, some parameters needed to be altered and some new ones introduced that would be suitable to the system.

## SAP Options

SAP has more than 50 options which need to be defined to prepare a compilable version. If one prepared a PLANK version of SAP, that program could define the options in the pre-processing run. The main SAP run can use those defaults, or modify some dynamic options during the executable processing. Such a program was prepared by the author and currently resides in the SAP directory under the name SPLANK. However, unlike HULL, fewer options in SAP require dynamic alteration. Therefore one could skip the use of SPLANK and directly introduce the options during the update/generate mode of SAIL.

Some options also have dependency on other options. Therefore care must be exercised in altering them. Appendix A shows a list of default and redefined options as listed by SAIL during pre-processing of SAP. SAP was added to the HULL system as the procedure RUNSAP. Some of the printed options in the list therefore come from the HULL options and the system parameters. Appendix B, which was reproduced from [4], gives a list of SAP options and overviews of the subroutines in SAP. One must keep the default options in mind while upgrading the SAP system. The defaults need not be altered at all if the physical problem does not require it. In the present CRAY version of SAP, the user needs to choose the following options:

1) SAPNM - represents the number of materials in the problem.
2) SAPMX - represents the maximum grid size.
3) SPGEOM - chooses the type of geometry in the run.
(Cartesian - 1, Cylindrical - 2 and Spherical -3)
4) SPMTHD - chooses between differencing techniques in the solution process.
5) NMAT - represents the number of material boundaries in the problem. Note that this number may be larger than SAPNM, depending on the arrangement of materials.
6) RESTART \& HYDRA - These are similar options. The latter should be chosen to generate a restart file, whereas the former should be chosen when a restart file already exists.
7) BURN = 1 must be used if explosives are present in the problem. In those cases, the explosives can have both burned and unburned choices (material name preceded by "B").
8) Other important options include RAD, VISC, ACM and FCT to specify physical and computational choices, whereas SPUTIN, HCUTIN and PLOTIT give pre- and post-processing choices.

After the pre-processing SAIL run produces a compilable SAP, it must be compiled, linked and executed with a proper SAP input. See the example in Appendix C. SAP inputs have generally three sections.

The first section starts with the keyword "sap". This section enters the problem number and starting requests in terms of time and cycles. The problem number and starting information must be carefully inputted on a restart run, the failure of which will immediately abort the run.

The second section starts with the keyword "input". This section has the stopping request, the header block definition and definitions of the " $z$ block" parameters. These parameters are upgraded at each run and therefore some of these can be considered as dynamic options. A complete list of the $z$ block parameters are available in appendix $D$.

The last section starts with the keyword "region". This is similar to the keyword "mesh" in KEEL runs. It has six different variables separated by the word CELLS. These variables are - material name, dx, energy, rho, speed, and bound. Material names have to be used exactly as they were introduced in the SAIL pre-processing. DX represents the width of cells in this part of the mesh.

Energy and rho represent the energy and mass densities. All units are expressed in the CGS (Centimeters, Grams, Seconds) unit system. Speed represents the speed of the material in this part of the mesh. Again, this quantity is expected to be a variable. The first cell must be assigned some initial velocity. A zero velocity input for the first cell will result in aborting the program. Bound represents the maximum number of cells for which the previous five variables hold. The default on bound is IMAX, the maximum number of cells in the problem. If there are several materials present in the problem, the bound values should be inputted carefully.

All of the above six variables may not be specified in a given problem. For example, the sample input in Appendix $C$ has three materials - BPENT, PENT and AIR. The problem stacks up BPENT in the first cell, PENT in Cell 2 through 77 and AIR for Cells 78 through 100. The mesh size is a variable. As may be noticed from this example, only 4 variables (out of 6 ) were defined in the first three cells, 3 were defined between Cells 4 through 77 and only two were defined for the rest of the mesh. Further descriptions of input variables are presented in Appendix D.

The final word in the sap input is "end". Once these inputs are correctly specified, SAP outputs a "sap.out" and a "tape 4" (if option hydra is chosen).

Appendix E shows the sequence of the batch run "jobsap.com". This batch job prepares the compilable version from the card input [4], compiles, links, and executes the program with the SAP input shown in Appendix $C$. The output "sap.out" is presented in Appendix F. It can be seen from the output that the program generates the $z$-block and the mesh configuration correctly.

This particular run has a problem in the subroutine "BURN", as reflected in the output. This code, like any other newly developed capability, has to be tested in various physical problems before confident statements can be made regarding its advantages and drawbacks. The error source is probably among input or material properties data or methodology of calculations. Further testings are currently in progress.

## Conclusions and Recommendations

The SAP code was added to the HULL library of programs at WES. This code will provide an input for the HULL calculations, or it can produce onedimensional solutions for airblast problems independently. The code remains to be tested in various physical problems.

One very useful application of the code will be to use it in the airblast calculations presented in [2]. It would be interesting to know whether SAP outputs can be inputted into HULL calculations with significant improvement in the overall run time of the HULL calculations. Another interest would be to see if the HULL input thus generated by the "firein" option in KEEL would produce a better arrival time of the shock at ground zero in the HULL run than was obtained previously.

SAP can also be used in the reverse mode, where HULL outputs are used as input to SAP by the program HULLCUT, which takes a slice of the multidimensional output. Finally, the newly-added capability of onedimensional calculations can produce approximate and quick answers to significantly large problems as a stand-alone capability, where an early prediction can influence later decision making.

1. M.A. Fry, R.E. Durrett, G.P. Ganong, D.A. Matuska, M.D. Stucker, B.S. Chambers, C.E. Needham and C.D. Westmoreland, "The HULL Hydrodynamics Computer Gode", Technical Report No. AFWL-TR-76-183, September 1976.
2. A. Ghosh, "Centerline Discrepancies in HULL Axisymmetric Calculations", Final Report, Contract DAALO3-91-C-0034, TCN: 92007, presented to the Waterways Experiment Station, May 15, 1992.
3. W.A. Whitaker, E.A. Nawrocki, C.E. Needham and W.W. Troutman, Theoretical Calculations of the Phenomenology of HE Detonations", Technical Report No. AFWL-TR-66-141, November 1966.
4. The SAP Code: Source obtained from Applied Research Associates, Inc., Vicksburg, MS 39180, June 19, 1992.
5. D.A. Matuska and J.J. Osborn, "HULL Documentation, Volume I and II", Orlando Technology, Inc., Shalimar, Florida 32579, 1990.
6. J. Hilsenrath, M.S. Green and C.W. Beckett, "Thermodynamic Properties of Highly Ionized Air", SWC-TR-56-35, National Bureau of Standards, Washington, D.C., April 1957

## Appendix A

sail library for version
generated
3 aug92

0 this library contains 140358 lines
0 generating source from programs on 3aug92
0 program origin program origin

0 *sap 210000
0 programs which are marked with an * will generate source in this run
1 options defined at the beginning of this run

| 0 | inst | = | 16 | mach | = | 1 | sail | = | 0 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | runsap | = | 1 | tekcolor | = | 0 | eos | = | 0 |
| 0 | matlib | = | 0 | plank | = | 0 | common | = | 0 |
| 0 | proc-msc | $=$ | 0 | hull | = | 0 | plotters | = | 0 |
| 0 | pull | = | 0 | station | = | 0 | plotvg | = | 0 |
| 0 | keel | = | 0 | Irez | = | 0 | sap |  | 2 |
| 0 | staplt | = | 0 | hullcut | = | 0 | sapplt |  | 0 |
| 0 | library | = | 0 | control | = | 0 |  |  |  |

loptions defined/redefined during executive processing

| cray | $=$ | 1 |
| :--- | :--- | ---: |
| opsys | $=$ | 2 |
| vendor | $=$ | 1 |
| pf | $=$ | 1 |
| objlib | $=$ | 0 |
| tapelib | $=$ | 3 |
| plotpkg | $=$ | 0 |
| remark | $=$ | 0 |
| mf | $=$ | 0 |
| cdc | $=$ | 0 |
| ibm | $=$ | 0 |
| cray | $=$ | 1 |
| vax | $=$ | 0 |
| sel | $=$ | 0 |
| vsos | $=$ | 0 |
| colour | $=$ | 0 |
| word | $=$ | 64 |
| byte | $=$ | 8 |
| date | $=$ | 2 |
| buffer | $=$ | 1 |
| sensesw | $=$ | 1 |
| nw | $=$ | 1 |
| cw | $=$ | 8 |
| cardl | $=$ | 10 |


| cardo | = | 8 |
| :---: | :---: | :---: |
| double | = | 0 |
| exbl | = | 0 |
| debugl | = | 0 |
| debugs | = | 0 |
| mach | = | 1 |
| cde | = | 0 |
| univac | = | 0 |
| vax | = | 0 |
| cel | = | 0 |
| ridge | = | 0 |
| spsvth | = | 0 |
| sapmx | = | 100 |
| spgeom | = | 3 |
| spmthd | = | 1 |
| sapnm | = | 3 |
| single | = | 0 |
| airopt | = | 1 |
| atmos | = | 2 |
| compare | = | 0 |
| nstat | = | 0 |
| nmat | = | 3 |
| matt | = | 24 |
| air | = | 3 |
| tnt | = | 0 |
| btnt | = | 0 |
| pbx | = | 0 |
| bpbx | = | 0 |
| pent | = | 2 |
| bpent | = | 1 |
| anfo | = | 0 |
| banfo | = | 0 |
| meth | = | 0 |
| bmeth | = | 0 |
| water | = | 0 |
| hmx | = | 0 |
| bhmx | = | 0 |
| comb | = | 0 |
| bcomb | = | 0 |
| foam | = | 0 |
| cfour | = | 0 |
| bcfour | = | 0 |
| petn | = | 0 |
| bpetn | = | 0 |
| irmt | = | 0 |
| birmt | = | 0 |
| plug | = | 0 |
| rezone | = | 1 |
| method | = | 1 |
| lbnd | = | 0 |
| rbnd | = | 0 |
| imax | = | 100 |


| restart | $=$ | 0 |
| :---: | :---: | :---: |
| ktstd | $=$ | 0 |
| weight | = | 1 |
| ngroup | $=$ | 0 |
| sputin | = | 0 |
| hcutin | $=$ | 0 |
| hydra | = | 1 |
| acm | = | 0 |
| burn | = | 1 |
| fct | = | 0 |
| rad | = | 0 |
| nm | = | 3 |
| plotit | = | 0 |
| geom | = | 3 |
| visc | = | 1 |
| euler | = | 0 |
| jwl | = | 1 |
| cray | = | 1 |
| unicos | = | 1 |
| eos | = | 1 |
| sum | = | 1 |
| route | = | 0 |
| sys | = | 2 |
| nchpwd | = | 8 |
| nodpwd | = | 22 |
| nbitpc | = | 8 |
| nchar | = | 16 |
| lev | = | 1 |
| vector | = | 0 |
| asciim | = | 1 |
| disspl | = | 0 |
| scaler | = | 1 |
| nvarpr | = | 500 |
| nh | = | 5 |
| nbitpw | = | 64 |
| nshift | = | 32 |
| nshifl | = | 56 |
| nchmen | = | 2 |
| nwpev | = | 2 |
| nzblk | = | 100 |
| indxz | = | 200 |
| nzblk2 | = | 200 |
| idim | = | 300 |
| ijump | = | 101 |
| ijptwo | = | 201 |

02856 cards generated
1
0
end of normal sail run system hull version124

## Appendix B



$=$
(method 1) 20 feb 87 =
(method 2) 20 feb 87
=
as $\quad 20 f \mathrm{eb} 87$
=
method 1) 20 feb87
=
20 feb87
=
must 20 feb87
=
20 feb 87
$=$
20 feb87
$=\quad$ rbnd 0
only) $20 f e b 87$
=
20 feb87
20 feb87
$=$
20 feb87
=
permitted $20 f e b 87$
=
the 20 feb87
=
20 feb87
20 feb87
=
imposed 20 feb87
=
called $20 f e b 87$
=
(method 2) 20 feb87
=
as $\quad 20 \mathrm{feb} 87$
=
20 feb87
method 2 20 feb87

20 feb87
20 feb87
weight $20 f e b 87$
$=$
"lbound(time, distance, u,rho,i)"
"Ibound(time, u, rho,i)"
which specifies speed, density and energy
a function of time (and distance, if must be loaded.
also, the parameter "lbref" set by input be zero, indicating a transmissive left boundary
right boundary condition option (method 2 $=0$ right boundary condition is defined by the option 'rezone'
$=1$ the right boundary is reflective. the sap variable 'shkcel' will never be to have values greater than imax -2 , and calculation will not terminate when shkcel reaches a value of imax - 2 . $=2$ there is a right boundary condition if ktstd=0, a right boundary subroutine
"rbound(time, u, rho, i)"
which specifies speed, density and energy a function of time must be loaded. differencing scheme option $=1$ old sap differencing
$=2$ hull differencing
weight option for method 2
$=1$ conventional hull boundary algorithm




c) bpent,pent,air 20 feb87
d) water, bpent, pent, water 20 feb87
e) bpent, pent, tnt, pent, air 20 feb87

20 feb87
should have the following options set as shown20 feb87

20 feb87
20 feb 87
20 febs 7
20feb87

20 feb87
C) 3

312
1 bpent=1, pent=2, air=3 20 feb87
d) 3
$4 \quad 12$
$20 f e b 87$
e) $20 f \mathrm{eb} 87$

20 feb87
except for a) (obviously) the ordering of the 20 feb87
material code numbers is arbitrary (the fifth column 20 feb87
of the above example is not unique). note that the 20 feb87
last zone in the mesh must be included as a material 20 feb87
boundary. 20 feb87

## 20 feb87

sap consists of a fair number of subroutines linked by $20 f e b 87$
blank and labeled common. in addition to the summary 20 feb87
given below, most of the subroutines contain further 20 feb87
explanation of their functions. for a detailed 20 feb87
description of card input to sap, see subroutine in. 20 feb87
the section labeled "constant" in sap outlines the 20 feb87

20 feb87
20 feb87 20 feb87 20 feb87 20 feb87
20 feb87 hydro -
card input to sap (see in for explanation of input format)
tape input (tape4,tape9) restart
if applicable (hydra)
sets up mesh using input
defines $2 b l k$ default values before input is read places input that is read into the $z b l k$ (from tape or card input) into appropriate problem parameters
prints the initial zblk and the problem configuration.
main loop routines
selects time step for next cycle calculates hydro variable values throughout active mesh for the current cycle.



## Appendix C

```
sap prob=111.0 t=1.e-4
    cycle=0.0 input cstop=2100 detcel=1.0 rdw=11.0
    angle=0.0 head
    sap run pentolite 100 cells 29 july }9
    hob=0.0 x0=0.0
    region
            bpent=1 speed=.01 dx=11.0 bound=1 cells
            speed=.01 pent=2 dx=10. bound=3 cells
            pent=2 dx=10.0 bound=75 cells
            air=3 dx=30. bound=77 cells
    air=3 dx=42. cells
end
```


## Appendix D

## subroutine in

20 feb87
C
20 feb87
 ******* 20feb87
c*

* 20feb87
c* this subroutine reads the card input to sap and places the * 20 feb87
c* values in the proper parameters.
* 20feb87
c*
* 20 feb87

******* 20 feb87

C


20 feb87
parameter (nmat $=$ _nmat_) 11feb87
equivalence (what, iws) 20 feb87

20 feb87
input to sap is divided into several sections separated 20 feb87 by keywords given below. all input is in free format. 20 feb87

20 feb87
the first keyword is "sap" and must in all cases be the 20 feb87
first word of data. three parameters follow 20 feb87
$t=$ (time for start of this run. if not present, default 20 feb87
is to a large value, indicating a restart at the end of 20 feb87
the last run. the time may not be .le. zero. if input as 20 feb87
such the program will stop) 20 feb87
prob $=$ (problem number) 20 feb87
cycle $=$ (cycle number for start of this run. for a new 20 feb87 problem, cycle=0.0. default is to a large

```
    value,indicating 20feb87
```

    \(=\quad\) a restart at the end of the last run. any other positive
        20 feb 87
            number will result in a restart at that cycle number)
        20 feb87
    = for a new problem, time and cycle must both be specified.
        20 feb87
    \(=\) for a restart neither need be input. failure to specify
        20 feb87
    \(=\) the correct problem number on a restart will cause sap to
        20 feb87
    \(=\) abort.
        20 feb87
    $=$
20 feb87
$=\quad$ for the previous two sections, the data input may appear
more $20 f \mathrm{feb} 7$
$=\quad$ than once. the latest value will be the one used by the
program. $20 f e b 87$
$=$ this is convenient when running two or more problems which
differ $20 f e b 87$
$=\quad$ only in the values of the input parameters. input cards may
be 20 feb87
$=$ reordered, rather than redone.
20 feb87
=
20 feb87
the next section is delimited from the first by the word
20 feb87
$=$ "input". data contained in this section pertain to zblock
20 feb87
$=$ parameter values, header card information, and the station
20 feb87
= coordinates if applicable. with the exception of the header
$20 f e b 87$
$=$ card, any values in this section may be defaulted to
internally $20 f e b 87$
$=$ set values listed below. data in this section may appear in
20 feb87
$=$ any order with two exceptions. the header card must be
20 feb87
on a separate card, preceded by the word "head", and the
$20 f e b 87$
station coordinates or data for generation of stations must
20 feb87
word default definition 20 feb87




(gm/cm**3). default is ambient density.

20 feb87
1). 20 feb 87
=
the 20 feb87
=
$=$
$20 f \mathrm{eb} 87$
$=$

- bound
$=$ bound 20 feb87

20 feb87

20 feb87
20 feb87
20 feb87
speed 20 feb87

20 feb 87
$=$ $20 f$ eb87

20 feb87

20 feb87
20 feb87 20 feb87 20 feb87 20 feb87
$20 f e b 87$
20 feb87 20 feb87
$20 f$ eb87
20 feb87 $20 f e b 87$
these six words may appear in any order within a group.
they must be followed by the word "cells". groups must be
given in order of increasing distance from the center of the
problem. of course groups may not be mixed.
the final word of data input on cards must be the
as an example, a data set for a new problem consisting
speed of material in this part of the mesh. at least the first cell must be assigned some small initial velocity (if less than umin, initial velocity will not be present by cycle if there is a zero velocity in the first cell program will stop. default is $0.0 \mathrm{~cm} / \mathrm{sec}$.
maximum cell number for which the previous five values hold (default - bound=imax)

```
                20feb87
```

$=$ speed $=.01$ pent=3 $d x=10$. bound=3 cells
$20 f e b 87$ and the remaining 25 cells air at ambient conditions follows. $20 f e b 87$
fifty stations at intervals of $25 . \mathrm{cm}$ are generated. the 20 feb87
material codes are presumed to be identical with those input sail options. imax and nstat=no of stations are also set by 20 feb87
sail options.
20 feb87
20 feb87
sap prob=2001.00 t=1.e-4 20 feb87
cycle=0.0 input cstop=2100. detcel=1.0 rdw=11.0 20 feb87
angle=0.0 head
20 feb87
20 feb87
hob=0. 0
20 feb87
region
20 feb87
bpent $=2$ speed $=.01$ dx=11.0 bound=1 cells
20 feb87
pent=3 bound=75 $\mathrm{d} x=10.0$ cells
20 feb87
air=1 $d x=30$. bound=77 cells
20 feb87
air=1 $d x=42$. cells
20 feb87
20 feb87
20 feb87
20 feb87
$20 f e b 87$ 20 feb87
the previous run-s stop limit (cstop, dstop, or ptstop) with 20 feb87
the rest of the data unchanged will result in a restart $20 f e b 87$
beginning where the last run stopped. any changes in input 20 feb87
will take precedence over tape4 values obtained from the

```
sap run pentolite 100 cells 4 apr 75
deletion of the statement cycle \(=0.0\) and an increment of
```

20 feb87
$=\quad$ the zblock, except of course those parameters which change 20 feb87
$=$ with time (eg - detcel,rdw,shkcel). if restarting before a 20 feb87
$=$ rezone has occurred, the inactive portion of the mesh 20 feb87
$=$ (cells shkcel+2 to imax) will be restuffed with the 20 feb87
= appropriate data from the "region" section. if a remesh has 20 feb87
$=$ taken place in the previous run, the inactive cells are 20 feb87
$=\quad$ initialized at ambient air conditions with a width equal to 20 feb87
$=$ the last undisturbed cell in the mesh
(x(shkcel+1)-x(shkcel)). 20 feb87
$=$ in this case, the "region" data is ignored and may be deleted 20 feb87
$=$ (omit the keyword as well). in all cases "end" must mark the 20 feb87
$=\quad$ end of the sap card data. 20 feb87
$=$
20 feb87
$=$
20 feb87
$=\quad$ an example of a problem using sputter data as input is
the 20 feb87
following.
20 feb87
20 feb87
$=$
20 feb87
$=\operatorname{sap} t=1 . e-3 \quad$ prob=1313.00 cycle=0.00
20 feb87
$=$ input angle $=0.0$
20 feb87
head
20 feb87
$=\quad$ sputter input example\$ 20 feb87
$=$ sputin yield=2.0 hob=5.e5 scale fb=fb21 $d x=.2$ 20 feb87
$=$ end
20 feb87
$=$
20 feb87
$=\quad$ Where the sputter tape fb21 is used with data from a dump closest 20 feb87
$=$ to but latter than 1.e-3sec. this data will be scaled to a

2 kt 20 feb87
$=$ burst at 5 km . the remaining cells will be .2 cm filled with 20 feb87
$\begin{array}{ll}= & \text { ambient } \\ \text { card } & 20 f e b 87\end{array}$
$=\quad$ as a string terminator. 20 feb87
$=$ 20 feb87

## Appendix E

```
# Batch File jobsap.com
            embedded NQS options
e$-eo # directs stderr to stdout
@$-1t 0:30:00 # per-process CPU time
e$-1T 0:30:00 # per-request CPU time
@$ # end of embedded NQS options
Add SAP to the HULL Library
#
cd /u2/h5serag0/sap
#
ln /u2/h5serba0/HULL122/hull122.system old
#
cat >sail.in <<EOF
sail version 122.1 update
*i 189999
*b runsap
*keepto runsap runsap eq1
*read modif.cr
*label runsap
EOF
sail <sail.in >sail.s.out
ln new sapv1.system
rm -f new old
#
# Re-Sequence HULL Library
ln sapv1.system old
#
cat >sail.in <<EOF
sail version }123\mathrm{ update
seq program runsap
EOF
sail <sail.in >sail.s.out
ln new sapv2.system
rm -f new old
##
This converts the program runsap from the hull binary
to ascii format
                                    (Stored in sapv1.system)
ln sapv2.system old
#
cat >sail.in <<EOF
sail copy convert
EOF
```

```
sail <sail.in >sail.s.out
In new runsap.ascii
rm -f new old
## This prepares coded hull library of runsap
    from runsap.ascii
```

```
#
```


# 

ln runsap.ascii old
ln runsap.ascii old

# 

# 

cat >sail.in <<EOF
cat >sail.in <<EOF
sail convert copy
sail convert copy
EOF
EOF
sail <sail.in >sail.s.out
sail <sail.in >sail.s.out
ln new sapv3.system
ln new sapv3.system
rm -f old new
rm -f old new

# 

# 

ln sapv3.system old
ln sapv3.system old

# 

# 

cat >sail.in <<EOF
cat >sail.in <<EOF
sail lineno options runsap=1 endoptions program sap
sail lineno options runsap=1 endoptions program sap
EOF
EOF
sail <sail.in >sail.s.out
sail <sail.in >sail.s.out
mv source sap.f
mv source sap.f

# 

# 

cat >segldr.in <<EOF
cat >segldr.in <<EOF
preset=-indef
preset=-indef
abs=sap
abs=sap
bin=sap.o
bin=sap.o
EOF
EOF

# 

# 

cft77 -a static -1 sap.l sap.f
cft77 -a static -1 sap.l sap.f
segldr segldr.in
segldr segldr.in

# 

# 

time sap <sap.in >sap.out
time sap <sap.in >sap.out

# 

```
#
```


## Appendix $F$

1 sap run pentolite 100 cells 29 july 92

imax
lbref method
nh
nstat
nvarpr
nzblk
prdw
ptstop
qmin
rad
radsum
rdw
rezone
shkcel
stabf
t
thm
umin
visc
yield
nmat
bpent
pent
air
sap run
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
0.0000E+00
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$ pentolite
$1.0000 \mathrm{E}+02$

1. $0000 \mathrm{E}+00$
2. $0000 \mathrm{E}+00$
$5.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$2.5000 \mathrm{E}+01$
$4.2000 \mathrm{E}+01$
$0.0000 \mathrm{E}+00$
3. $0000 \mathrm{E}+02$
1.0000E-01
$0.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$1.1000 \mathrm{E}+01$
$1.0000 \mathrm{E}+00$
4.0000E+00
8.0000E-01
$1.0000 \mathrm{E}-04$
$7.0947 \mathrm{E}+08$
$1.0000 \mathrm{E}-04$
$1.0000 \mathrm{E}+00$
$0.0000 \mathrm{E}+00$
$3.0000 \mathrm{E}+00$
$1.0000 \mathrm{E}+00$
4. $0000 \mathrm{E}+00$
$3.0000 \mathrm{E}+00$
100 cells
29 july 92

mesh values start of this run

$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.21235 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 16$
$17 \quad 1.71000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.37270 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+0111$
$18 \quad 1.81000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.54302 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 18$
$19 \quad 1.91000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.72330 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 19$
$20 \quad 2.01000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.91353 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 20$
$21 \quad 2.11000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.11373 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 21$
$22 \quad 2.21000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.32388 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 22$
$23 \quad 2.31000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1$.
$.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.54400 \mathrm{E}+06$
$2412.41000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.77408 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 24$
$25 \quad 2.51000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 3.01411 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 25$ $26 \quad 2.61000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 3.26411 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 26$
$27 \quad 2.71000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 3.52406 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 27$ $28 \quad 2.81000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 3.79398 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 28$ $29 \quad 2.91000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 4.07386 \mathrm{E}+06$
$1.00000 \mathrm{E}+01$
$30 \quad 3.01000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 4.36369 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 30$ $31 \quad 3.11000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 4.66349 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 31$ $32 \quad 3.21000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 4.97324 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01$ $33 \quad 3.31000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 5.29296 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 33$ $34 \quad 3.41000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 5.62264 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 34$ $35 \quad 3.51000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 5.96227 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 35$ $36 \quad 3.61000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 6.31187 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01$ $37 \quad 3.71000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 6.67142 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01$ $38 \quad 3.81000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 7.04094 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 38$ $39 \quad 3.91000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 7.42042 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01$ $40 \quad 4.01000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 7.80985 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01 \quad 40$ $41 \quad 4.11000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 8.20925 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01$
42
4.21000E+02
$0.00000 \mathrm{E}+00$
$1.01325 \mathrm{E}+06$
$1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$ ..... 8.61860E+06
$1.00000 \mathrm{E}+01$ ..... 42
$43 \quad 4.31000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$ $9.03792 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01$ ..... 43
$44 \quad 4.41000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$ $9.46720 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+01$ ..... 44
$45 \quad 4.51000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$ $9.90643 \mathrm{E}+06$ $1.00000 \mathrm{E}+01$ ..... 45
$46 \quad 4.61000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00$ $1.03556 \mathrm{E}+07$ $1.00000 \mathrm{E}+01$ ..... 46
$47 \quad 4.71000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ 1. $01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$ $1.08148 \mathrm{E}+07$ 1.00000E+01 ..... 47
$48 \quad 4.81000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.12839 \mathrm{E}+07$ $1.00000 \mathrm{E}+01$ ..... 48
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$
49 4.91000E+02 $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00$$1.17630 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01$49
$50 \quad 5.01000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$ $1.22520 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01$ ..... 50
1 sap run pentolite 100 cells ..... 29 july 92
problem $111.00000 \quad$ cycle $=\quad 0 . \quad t=1.00000 \mathrm{E}-04$ total energy eth $=8.34180 \mathrm{E}+16 \quad$ total mass thm $=7.09472 \mathrm{E}+08$
mesh values start of this run
rho ${ }_{\text {temp }}$ u
zm
$5.11000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$
1.00000E+08
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.27510 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01$ ..... 51
52 $5.21000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.32600 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01$ ..... 52
$53 \quad 5.31000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00$ 1.37789E+07 $1.00000 \mathrm{E}+01$ ..... 53
$545.41000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00$ $0.00000 \mathrm{E}+00$$1.43078 \mathrm{E}+07$$1.00000 \mathrm{E}+01$54
$55 \quad 5.51000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00$ $1.48466 \mathrm{E}+07$ 1.00000E+01 ..... 55
56 $5.61000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.53954 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01$ ..... 56
$575.71000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00$ $1.59541 \mathrm{E}+07$ $1.00000 \mathrm{E}+01$ ..... 57
$58 \quad 5.81000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00$ $1.65229 \mathrm{E}+07$ $1.00000 \mathrm{E}+01$ ..... 58
$595.91000 \mathrm{E}+02$ $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.71015 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01$
60 6.01000E+02 $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.76902 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 60$
$61 \quad 6.11000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.82888 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01$ ..... 61
$62 \quad 6.21000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ $1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00$ $1.88973 \mathrm{E}+07$ $1.00000 \mathrm{E}+01$ ..... 62
63 6.31000E+02 $0.00000 \mathrm{E}+00$ $1.01325 \mathrm{E}+06$ 1. $00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 1.95158 \mathrm{E}+07$
$1.00000 \mathrm{E}+01$

63 $64 \quad 6.41000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.01443 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01^{1.000} 64$ $65 \quad 6.51000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.07828 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 65$ $66 \quad 6.61000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.14311 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 66$ $67 \quad 6.71000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.20895 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01^{1.000} 67$ $68 \quad 6.81000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.27578 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01^{1.000} 68$ $69 \quad 6.91000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.34361 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 69$ $70 \quad 7.01000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.41243 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 70$
$71 \quad 7.11000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.48225 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 71$ $72 \quad 7.21000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.55307 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 72$
$73 \quad 7.31000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$
$1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.62488 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 73$
$74 \quad 7.41000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.69769 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 74$
$75 \quad 7.51000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 1.00000 \mathrm{E}+08$ $1.66000 \mathrm{E}+00 \quad 0.00000 \mathrm{E}+00 \quad 2.77149 \mathrm{E}+07 \quad 1.00000 \mathrm{E}+01 \quad 75$ $76 \quad 7.81000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 6.46981 \mathrm{E}+04 \quad 3.00000 \mathrm{E}+01 \quad 76$ $77 \quad 8.11000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 6.98644 \mathrm{E}+04 \quad 3.00000 \mathrm{E}+01 \quad 77$ $78 \quad 8.53000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.06867 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 78$ $79 \quad 8.95000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.17927 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 79$ $80 \quad 9.37000 \mathrm{E}+02 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.29531 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 80$
$81 \quad 9.79000 \mathrm{E}+02$
$0.00000 \mathrm{E}+00$
$1.01325 \mathrm{E}+06$
$2.04448 \mathrm{E}+09$
$1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.41680 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 81$
$82 \quad 1.02100 \mathrm{E}+03 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.54373 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 82$ $83 \quad 1.06300 \mathrm{E}+03 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.67610 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 83$ $84 \quad 1.10500 \mathrm{E}+03 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.81393 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 84$
$85121.14700 \mathrm{E}+03 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 1.95719 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 85$ $86 \quad 1.18900 \mathrm{E}+03 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 2.10591 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 86$ $87 \quad 1.23100 \mathrm{E}+03 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 2.26007 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 87$ $88 \quad 1.27300 \mathrm{E}+03 \quad 0.00000 \mathrm{E}+00 \quad 1.01325 \mathrm{E}+06 \quad 2.04448 \mathrm{E}+09$ $1.22500 \mathrm{E}-03 \quad 2.87938 \mathrm{E}+02 \quad 2.41967 \mathrm{E}+05 \quad 4.20000 \mathrm{E}+01 \quad 88$
89

1. $31500 \mathrm{E}+03$
$0.00000 \mathrm{E}+00$
$1.01325 \mathrm{E}+06$
$2.04448 \mathrm{E}+09$

| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $2.58472 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 89 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 90 | $1.35700 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $2.75521 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 90 |
| 91 | $1.39900 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $2.93115 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 91 |
| 92 | $1.44100 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $3.11254 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 92 |
| 93 | $1.48300 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $3.29937 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 93 |
| 94 | $1.52500 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $3.49165 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 94 |
| 95 | $1.56700 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $3.68937 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 95 |
| 96 | $1.60900 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $3.89254 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 96 |
| 97 | $1.65100 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $4.10115 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 97 |
| 98 | $1.69300 \mathrm{E}+03$ | $0.0000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $4.31521 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 98 |
| 99 | $1.73500 \mathrm{E}+03$ | $0.0000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $4.53472 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 99 |
| 100 | $1.77700 \mathrm{E}+03$ | $0.00000 \mathrm{E}+00$ | $1.01325 \mathrm{E}+06$ | $2.04448 \mathrm{E}+09$ |
| $1.22500 \mathrm{E}-03$ | $2.87938 \mathrm{E}+02$ | $4.75966 \mathrm{E}+05$ | $4.20000 \mathrm{E}+01$ | 100 |

## REPORT DOCUMENTATION PAGE



## 11. SUPPLEMENTARY NOTES

Task was performed under a Scientific Services Agreement issued by Battelle, Research Triangle Park Office, 200 Park Drive, P.O. Box 12297, RTP, NC 227709

12a. DISTRIBUTION/AVAILABILITY STATEMENT
12b. DISTRIBUTION CODE
Approved for public release; distribution is unlimited

## 13. ABSTRACT (Maximum 200 words)

The Spherical Air Puff (SAP) hydrocode was added to the HULL system at the U.S. Army Engineer Waterways Experiment Station (WES) to enhance the capabilities of hydrodynamic calculations. The program is intended to achieve faster execution time and better accuracy in certain hydrodynamic problems. SAP will furnish starting values in HULL hydrodynamic calculations, as well as being an independent capability. The enhanced capability must be tested with different physical problems.
14. SUBJECT TERMS

Air blast, HULL, Hydrodynamic calculations, SAP, Spherical
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