DEVELOPMENT OF A VISUALIZATION TOOL FOR THE ARIES SYSTEMS CODE

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A graphical user interface (GUI) is being developed by the ARIES team to visually display large amounts of system parameter data relevant to tokamak power plants. The objective of the Visual ARIES Systems Scanning Tool (VASST) is to harness the scanning power of the new systems code by filtering the tremendous amount of data and displaying it in an interactive and exploratory manner. The goal of the software tool is to better understand the tradeoffs between design parameters and to gain insight into parametric trends.

Progress has been made in creating a GUI that allows the user to intuitively and interactively create color-coded plots using any of the parameters within the database. Among other features, a user-input constraint allows the user to limit the parameter space to include/exclude certain ranges of data that are of interest.

VASST is being utilized in conjunction with system analysis scans for the ARIES studies reviewing aggressive and conservative physics and technology assumptions to help define tokamak power plants.

I. INTRODUCTION

The ARIES research program is committed to developing integrated design studies of fusion energy devices for the commercial utility sector. Part of the development route to a viable power plant, which is cost-competitive in the commercial market, has been the progressive study of integrated fusion power plant conceptual designs. An important tool in this developmental learning and optimization process is the exploration of design parameters through the use of the ARIES systems code (ASC), which has been developed by the ARIES team over several years.[1] Traditionally, the ASC was utilized in the ARIES-RS,[2] ST[3] and CS[4] studies to manipulate high-leverage parameters to minimize the COE. The ASC helped define and optimize the reactor about this specific design point, which often produced the most favorable power plant for a set of constrained parameter choices. However, it was often difficult to justify or understand why the point was optimal and the design was frequently very sensitive about that point.

For these reasons, the systems analysis approach was modified to use the ASC to scan a wide operating space for a range of possible design solutions rather optimize about one point. The ultimate goals are to more accurately understand the tradeoffs between the available systems parameters and then to identify where they have a strong or weak impact to create a better-motivated fusion device. Some parameters may be purposefully shifted in an adverse manner to compensate for a favorable tradeoff in other more stringent or costly areas. We want to have the ability to entertain tradeoffs or compromises that might very well have a minor influence on the design and cost of electricity (COE).

The new systems code consists of newly revised physics, engineering, and costing modules that can be swapped as required[1]. The new version also contains the ability to scan any of the 55 input parameters to any resolution. A detailed scan with the systems code could output millions of possible operating points. Hence, a key task of this new scanning approach is the ability to visualize the dependence of the multi-dimensional parameters on one another, to be able to extract meaningful data, and to provide direction to focus on more meaningful regions of the operating space. Such a visualization method must be able to identify trends and provide insight into the tradeoffs of the parameter space and ultimately the COE.

We are developing a visualization GUI called the Visual ARIES Systems Scanning Tool to filter the tremendous amount of data from the ASC and display it in an interactive and exploratory manner. VASST was created within the Matlab programming environment and allows the user to intuitively create plots of any parameter in the systems code output database against any other and color code a third parameter. DIII-D[5] and NIFS[6] are other institutions that employ visualization tools to display their data. These tools also seek to be user-friendly and flexible but are more specific to their operating facility and mainly seek to visualize and analyze experimental data. VASST is a unique tool that allows exploration of the multi-dimensional parameter space to display trends and relationships between the self-consistent design points of future tokamak power plants.

We have utilized VASST to help narrow down two "strawmen" points at two of the four corners of our tokamak parameter space, which is the combination of aggressive and conservative physics and technology. The strawmen will provide the ARIES team starting points for which further detailed analysis can be done.

II. MOTIVATION AND RESEARCH

The new scanning ability of the systems code has been the key motivation to design a visualization technique that can visually display the slopes and trends of various parameters plotted against each other. The results from a wide-ranged, coarse system scan would help hone in on specific, interesting areas where we could then increase the scanning resolution and ultimately verify the point(s) of interest with detailed analysis.

The commencement of this project began by looking at ways data is visualized in the world and how institutions and organizations use visualization methods to quickly and effectively illustrate large amounts of data. Visualizing large datasets is a difficult task, almost an art. Displaying more than a few million points on a computer screen will overwhelm the screen's pixels and data will be lost as new points pile on top of it. The key task of visualization is to gain insight into large amounts of data by displaying it visually to "low-bandwidth" observers.

The National Oceanic and Atmospheric Administration (NOAA) accesses data from thousands of buoys scattered through the world's oceans.[7] These buoys record a large amount of data including sea temperature, density, salinity, wind speed and direction, wave height, air pressure and humidity, all logged at minute to hour intervals or averaged over a wide range of time periods and oceanic regions. This data is even available to the public in near real-time on the internet. The large amount of data makes it difficult to understand or put to use by simply looking at the raw numbers streaming from the arsenal of buoys. NOAA visualizes this data by averaging it, color-coding it, overlaying it on maps, and making use of various simple plotting techniques such as two-dimensional (2D) and color surface plots for both instructional and scientific use.

Other institutions, such as the San Diego Supercomputer Center (SDSC) employ 4D (3D space over time) visualization methods to model earthquake simulations over varying terrain.[8] The simulations provide the researchers with an unparallel view of how the terrain interacts and amplifies the waves of energy released. Exploring data visually reveals many interesting features in the data set that might be lost otherwise.

The lessons and methods cultured from this research led us to employ the use of Matlab to create a GUI that would provide simple color plots and an intuitive user interaction interface. Two-dimensional plots with color-coding would maintain simplicity and not overburden or confuse the user with having to interpret 3D figures. We considered not only the technical aspect of the data being displayed, but also the user-interaction and interpretation aspect. We determined that three important items to make this project successful: an intuitive visualization tool, a capable and experienced user to interpret the results, and an in-depth chronicle of details so that the results and visualizations would not be lost or ambiguous.

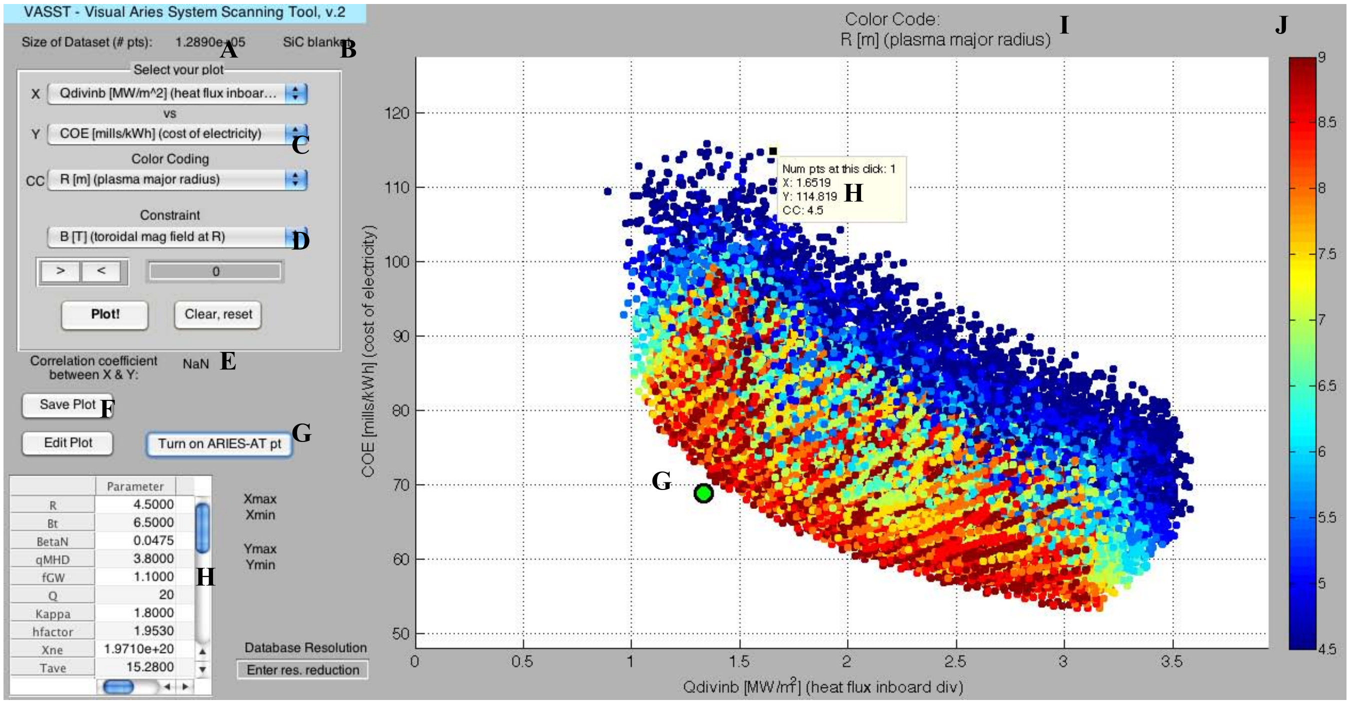
III. ASC OVERVIEW, FILTERING DATABASE

The new ARIES systems code was rewritten to provide the aforementioned scanning capability and also to generate an updated and more accurate model of an advanced, steady state tokamak power plant. The new flow strategy for the code created a general-purpose toolbox with "plug-in" modules that would allow them to be easily swapped for other designs. The code consists of three distinct modules, which are physics, engineering, and costing. The code is run by first submitting an input file to the physics module, which then solves the plasma power and particle balances. The engineering and costing modules then apply their appropriate algorithms to provide a self-consistent power plant design. This sequence is looped to cover the entire range of input values.

Since the systems code has the ability to scan any of the input parameters that define a tokamak reactor (e.g. radius, β_N, toroidal field, Greenwald density fraction, etc.), the output of the systems code can surpass millions of points. We have the capability to parallel process the engineering data on the Princeton Plasma Physics Lab (PPPL) cluster computer system, thus reducing computation time by the number of nodes employed. The approximate processing time is 2000 points per hour per node; a 1M point run takes ~50 hours using 10 nodes.

After the systems code has finished processing the database on the cluster computer, it is then downloaded to a local computer for preliminary filtering. The database must be filtered to remove points that do not meet the physics or engineering criteria and are not of interest. For the current ARIES Physics and Technology Assessment, we are interested in design points with net electric power of 1,000 ± 15 MW, inboard and outboard peak divertor heat fluxes of less than 15 MW/m^2, and a maximum toroidal field up to 18 T. All filtering is done in Matlab and is adjustable by the user.

After the preliminary filtering of the raw database is complete, the millions of points might be whittled down to ten's of thousands of possible points. The database may now be loaded into VASST, or further filtering can be done to hone in on a desirable machine or region of interest (e.g. R = 5.5 – 7 m, Greenwald density fraction < 1, $\beta_N = 0.04 – 0.05$, $H_{98} < 1.9$, COE < 70 mills/kWh, etc.).



VASST - Visual Aries System Scanning Tool, v.2

Size of Dataset (# pts): 1.2890e+05

SiC blanket

X: Qdivinb [MW/m^2] (heat flux inboar...

vs

Y: COE [mills/kWh] (cost of electricity)

Color Coding

CC: R [m] (plasma major radius)

Constraint: B [T] (toroidal mag field at R)

0

Correlation coefficient between X & Y: NaN

	Parameter
R	4.5000
Bt	6.5000
BetaN	0.0475
qMHD	3.8000
fGW	1.1000
Q	20
Kappa	1.8000
hfactor	1.9530
Xne	1.9710e+20
Tave	15.2800

Num pts at this click: 1
X: 1.6519
Y: 114.819
CC: 4.5

Figure 1. VASST graphical user interface: A) number of points in the database, B) blanket database used, C) pull-down menus for parameters to plot, D) constraint parameter to filter points on-the-fly, E) correlation coefficient, F) save or edit plot buttons, G) turn on ARIES-AT point design for comparison, H) populate table with a mouse click to display the point's relevant parameters, I) auto-labeling and auto-scaling, J) color scale bar of third dimension

IV. VASST FEATURES

The VASST GUI was developed using Matlab's built-in GUI tools. The Matlab code was written with speed, reliability and flexibility in mind. Internal reviews as well as reviews by the ARIES team helped improve the GUI and add important features. The core features of VASST are its ability to load and filter large databases from the ASC, call up any plot of any parameter, and manipulate the data displayed in a variety of ways.

As shown in Figure 1, the GUI displays the start-up user interface and loads the appropriate database in just a few seconds. The size of the database and the engineering blanket assumption in use are displayed near the top. The user is able to select from pull-down menus which parameters he or she would like on the abscissa and ordinate dimensions, as well as the third-dimension, the color-coding of the points. The pull-down menus contain 20 of the most relevant power plant parameters out of the 84 total, and more can be added as needed. The user can then click the "plot" button and the GUI will then display the visualization data. The user can also choose to filter, or constrain, some of the data. The constrained parameter does not necessarily have to be one of the parameters that are plotted, but the plotted points that exceed the constraint will be removed. If applicable, a correlation coefficient will be displayed showing how well the abscissa and ordinate parameters relate to each other. The axes are normally scaled and labeled automatically, but the user can manually intervene if required. The plot can then be saved in print-quality in a variety of image formats. There is a button to turn on the ARIES-AT point design if the user would like to see where it lies compared to the points in the current database. The user can also click on any point on the plot and the table in the lower-left corner will fill in with all the parameters that describe that point. This is useful to quickly see how that point compares with respect to the others, to check outliers, or to observe if trends are occurring among other parameters not displayed.

Future improvements include adding the capability to call up two simultaneous plots, perhaps on two separate screens in order to not hinder the one screen's real estate. This would allow further intuitive comparison of parameters and also allow common points between the two plots to be highlighted.

V. VISUALIZING SYSTEMS CODE OUTPUT

VASST has recently played a key role in helping to determine "strawmen" points for the current ARIES Physics and Technology Assessment. This assessment is seeking to explore the tokamak power plant parameter space and designate "four corners" at the four aggressive and conservative extremes of the operating space. The blanket employed mainly depicts the range of technology, which is the more conservative dual-coolant lead-lithium (DCLL) and more aggressive silicon-carbide (SiC). The physics range is depicted by ARIES-I (below the now wall beta limit) on the conservative side and ARIES-AT (above the no wall beta limit) on the aggressive side. These points are necessary to define so that more detailed engineering analysis can be done. It also allows the ARIES team to pursue detailed analysis on plasma edge and material interactions, and plasma facing component engineering in order to include these aspects in the design. Figures 2 - 5 below are examples of plots from VASST that are relevant to the recent strawmen.

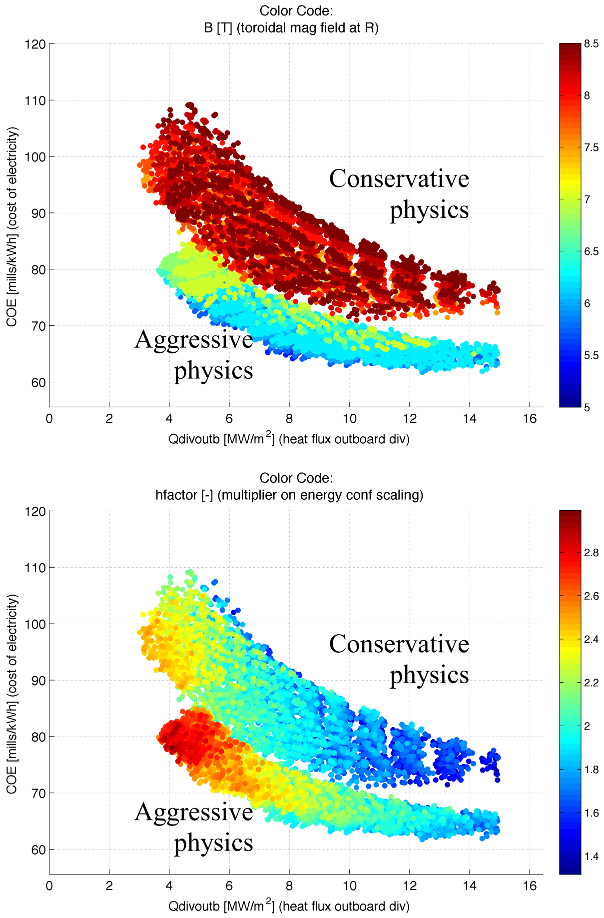


Figure 2. Plot of outboard divertor heat flux (Qdivoutb) vs. COE with color-code toroidal magnetic field (B) (top), and with color-code multiplier on energy confinement scaling (hfactor, H_{98}) (bottom). Two ranges of points can be distinguished; the conservative physics points in the top groupings and the aggressive ones in the bottom groupings. These plots both show the same data but with different color-coding. This allows the user to look at the same plotted points but visualize correlations across the third parameter. In this case, high magnetic fields and higher COE are found in the more conservative points for a given radius (top groupings) while low H_{98} and low COE are benefits of higher heat fluxes on the divertor.

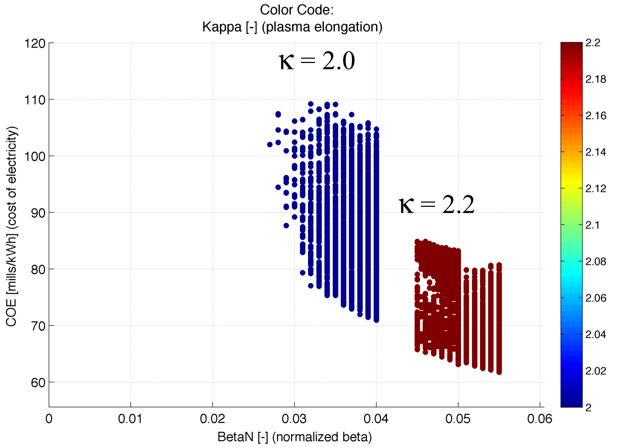


Figure 3. Plot of normalized beta (β_N) vs. COE with color-code plasma elongation (κ). The right grouping of points have a κ of 2.2 and are considered more aggressive while the left grouping have a κ of 2.0 and are more conservative. This plot shows how the less aggressive points have a lower β_N but higher COE. Notice the thickening of the database from $\beta_N \sim 0.045$ - 0.050, which was rescanned at higher resolution after promising potential machines were identified in the initial coarse scan. (Note that κ was chosen to be 2.2 and 2.0 for the aggressive / conservative cases, but it very well could have been scanned from 1.9 to 2.1 with 0.1 iteration steps for example.)

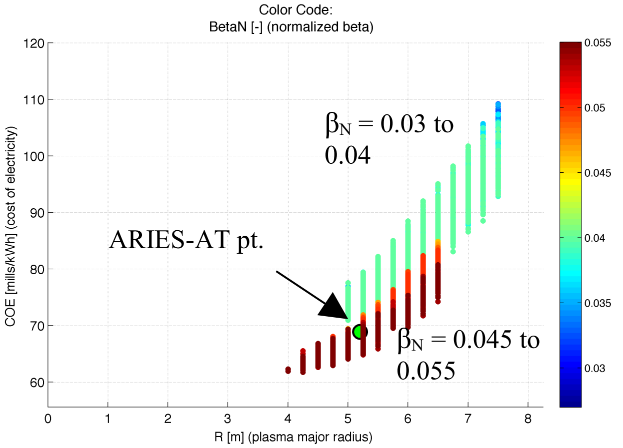


Figure 4. Plot of plasma major radius (R) vs. COE with color code β_N. Again, the two ranges of points can be differentiated, the conservative points in the top grouping and the aggressive ones in the bottom grouping. The ARIES-AT point has been turned on for comparison (R = 5.2 m, $\beta_N = 0.054$, COE = 68.9 mills/kWhr 2009$).

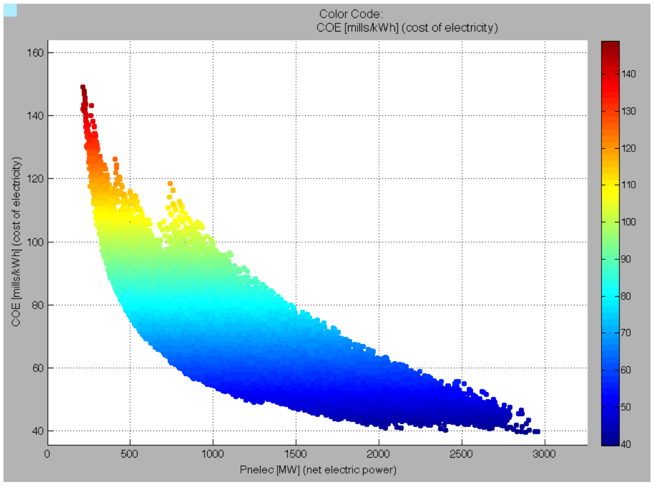


Figure 5. Net electric power (Pnelec) vs. COE with color-code COE. This plot shows the range of available self-consistent power plants with an unconstrained net electric power. It can be shown how the COE rises more strongly when Pnelec is less than ~ 800 MW due to the high capital cost of building a small power plant. On the right-hand side of the scale, the reduction in COE is small once the power plant output rises above ~ 1500 MW.

VI. DOCUMENTATION

Since large databases are being considered for the current systems analysis, it is vitally important that the database issued from the ASC to VASST be well documented and transparent so it can be referenced in the future. An ongoing document has been maintained that chronicles the vital parameters defining the databases in use. The chronicle maintains what version of the ASC and VASST were used, what input parameters were given, what blanket was employed, what assumptions were relied on in the code, what costing algorithms were used, and what filters were implemented. With this documentation plan we can assess our progress, refer to prior databases, enable transparency, and maintain the origin of the tokamak databases relevant to our systems studies.

VII. CONCLUSIONS

Progress has been made in developing an intuitive visualization tool with user interaction and simplicity in mind. VASST allows the user to interactively create plots using any of the parameters in the database and use color-coding to draw helpful comparisons and to illustrate trends within the self-consistent tokamak design space. Sample plots have been shown covering a wide range of scenarios with the most recent contribution to the four corner points of the ARIES Physics and Technology Assessment.

Future work may include expanding its capability to handle multiple plots that interact between each other and graphical motion. The ongoing goal is to improve the user interface to provide the user with a visually interactive and explorative tool that might help extract meaningful relationships from the tokamak databases.

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