Development of a Visualization Tool for the ARIES Systems Code to Explore the Parameter Space

Lane Carlson, Mark Tillack, Farrokh Najmabadi, Charles Kessel

University of California, San Diego & Princeton Plasma Physics Lab

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Systems code has evolved into a design space scanning tool

- Rather than optimize about a specific design point, new approach **scans** a wide **operating space** for a **range** of possible design points.

- It becomes necessary to **visualize** the large amount of data produced.

- We would like to better visualize tradeoffs and relationships between parameters.

- By relaxing an “optimized” constraint, a larger design **window** may open up and give a more robust and credible design with minimal impact on COE.
• Systems code consists of many modular building blocks
Now to visualize those points…

It is a challenge to visualize large data sets:

“Lots of numbers don’t make sense to ‘low-bandwidth’ humans, but visualization can decode large amounts of data to gain insight.”

- San Diego Super Computer Center
How do others visualize large data sets?

- Visualizing large datasets is a difficult task, almost an art.
- **Too much** information can be overwhelming/deceiving.
- $10^6$ points exceed computer monitor real estate.

NOAA (National Oceanic and Atmospheric Admin.) data-logging buoys
We have developed a visualization tool to utilize the scanning capability of the new systems code.

- **VASST - Visual ARIES Systems Scanning Tool**
- Desire to visualize the broad parameter space and to extract meaningful relationships
- Graphical user interface (GUI) permits 2D plots of any parameter

**Purpose:**
- give the user visual interaction and explorative power
- extract meaningful relationships
- understand design tradeoffs
VASST - Visual ARIES Systems Scanning Tool

- **Number of points in database**
- **Blanket used**
- **Pull-down menus for common parameters**
- **Auto-labeling**
- **Color bar scale**
- **Constraint parameter can restrict/filter database on-the-fly**
- **Correlation coefficient**
- **Save plot**
- **Edit plot properties**
- **Populate table with click**
- **Turn on ARIES-AT point design for reference**
Example: $Q_{divinb}$ vs COE, CC: $B_T$, constraint: $B_T < 8.5$ T
Example: Qdivinb vs COE, CC: $B_T$, constraint: $B_T < 7.5$ T
Example: Qdivinb vs COE, CC: $B_T$, constraint: $B_T < 7.0$ T
Example: Qdivinb vs COE, CC: $B_T$ constraint: $B_T < 6.5$ T
Example: \( Q_{\text{divinb}} \) vs COE, CC: \( B_T \), constraint: \( B_T < 6.0 \) T

SiC blanket
Example: $Q_{\text{divinb}}$ vs COE, CC: $B_T$, constraint: $B_T < 5.0$ T

Still many possible low COE designs exist at low $B_T$. 
We have explored the “four corners” for current ARIES Physics & Technology Assessment

- Scans have been performed to span the 4 corners of the parameter space
- VASST GUI has helped visualize the effects of filtering data and identified design tradeoffs.

<table>
<thead>
<tr>
<th>Aggressive in physics</th>
<th>Aggressive in technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARIES-AT physics</td>
<td>ARIES-AT physics</td>
</tr>
<tr>
<td>($\beta_N = 0.04$-$0.06$)</td>
<td>($\beta_N = 0.04$-$0.06$)</td>
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<tr>
<td>DCLL blanket</td>
<td>SiC blanket</td>
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<td>ARIES-I physics</td>
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<tr>
<td>($\beta_N = 0.03$)</td>
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<tr>
<td>DCLL blanket</td>
<td>SiC blanket</td>
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</tbody>
</table>
Some example systems code scanning parameters:

- **Preliminary filtering:**
  1. $\text{Pnelec} = 1000 \text{ MW} \pm 15 \text{ MW}$
  2. Divertor (in/outboard) limit $< 15 \text{ MW/m}^2$
  3. $B_T\text{max} = 6 - 18 \text{ T}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>R (m)</td>
<td>4.0 - 8.25</td>
<td>0.25</td>
</tr>
<tr>
<td>$B_T$ (T)</td>
<td>4.5 - 8.5</td>
<td>0.25</td>
</tr>
<tr>
<td>$\text{BetaN}$</td>
<td>0.025 - 0.06</td>
<td>0.005</td>
</tr>
<tr>
<td>Q gain</td>
<td>15 - 40</td>
<td>5</td>
</tr>
<tr>
<td>$n/n_{Gr}$</td>
<td>0.7 - 1.3</td>
<td>0.1</td>
</tr>
<tr>
<td>$P_{aux}$</td>
<td>5 - 40</td>
<td>5</td>
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<tr>
<td>...</td>
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</tbody>
</table>

System scans done on cluster computer with 100’s nodes

Large system scans can produce $10^6 - 10^8$ points
Net electric (unconstrained) vs. COE, CC: COE

SiC blanket

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

Filter Pnet elec = 1000 +/- 15 MW
Database name: SysoutFinalsiccomb3
(aggr phys & aggr/cons tech)

Filters: Bt 6-18 T
div (in, out) < 7.5 MW/m²
Pnlec = 1000 ± 15 MW
COE real
n/nGr < 1
H98 < 1.9

$\beta_N$ vs COE, CC kappa

Coarse and fine scans can be observed
**Database name:** SysoutFinalsiccomb3  
(aggr phys & aggr/cons tech)  

**Filters:** Bt 6-18 T  
div (in, out) < 7.5 MW/m²  
Pnelec = 1000 ± 15 MW  
COE real  
n/nGr < 1  

**Color Code:**  
hfactor [-] (multiplier on energy conf scaling)  

All H₉₈ shown  
1.6 - 2.8
Database name: SysoutFinalsiccomb3
(aggr phys & aggr/cons tech)
Filters: Bt 6-18 T
div (in, out) < 7.5 MW/m²
Pnelec = 1000 ± 15 MW
COE real
n/nGr < 1
H98 < 1.9

Color Code:
\text{hfactor [-]} \text{ (multiplier on energy conf scaling)}

\begin{itemize}
\item \textbf{Conservative physics}
\item \textbf{Aggressive physics}
\item \textbf{Filtered H}_{98} < 1.9
\end{itemize}
**Database name:** SysoutFinalsiccomb3  
(aggr phys & aggr/cons tech)  

**Filters:** Bt 6-18 T  
div (in, out) < 7.5 MW/m²  
Pnelec = 1000 ± 15 MW  
COE real  
n/nGr < 1

<table>
<thead>
<tr>
<th>SiC</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₉₈</td>
<td>&lt; 1.9 aggr,</td>
</tr>
<tr>
<td></td>
<td>&lt; 1.6 cons</td>
</tr>
</tbody>
</table>

**Color Code:**  
Kappa [-] (plasma elongation)
Aggr physics / aggr tech filtering (1/3)
Aggr physics / aggr tech filtering (2/3)

R vs $H_{98}$, CC COE

$f_{GW} < 1.0$
Aggr physics / aggr tech filtering (3/3)

R vs $H_{98}$, CC COE

$f_{GW} < 1.0$

$H_{98} < 1.7$
"Knee in the curve" at $\beta_N \sim 0.035$
Example: $R$ vs. $\beta_N$ vs COE, CC $H_{98}$

Conservative devices are large and costly at low $\beta_N$. 

**Graph:**
- **X:** $R$ [m] (plasma major radius)
- **Y:** $\beta_N$ [-] (normalized beta)
- **Color Coding:** COE [mils/kWh] (cost of electricity)
- **Constraint:** $B$ [T] (toroidal mag field at $R$)

**Correlation coefficient between X & Y:** -0.097

**Parameters:**
- $R$
- $Bt$
- $\beta_N$
- $\eta_{MH}$
- $fGW$
- $Q$
- $\kappaappa$
- $\xi^0$
- $\xi^\pm$
- $Tave$
- $\xi^0_{\eta}$

**Save Plot**
**Edit Plot**
**Plot!**
**Clear, reset**
Example: Cons physics / aggr tech

$B_T$ vs COE, CC $\beta_N$

Low $\beta_N$ regime
Example: Cons physics / aggr tech

$B_T$ vs COE, CC $\beta_N$

$\beta_N < 0.035$
Example: Cons physics / aggr tech
Managing the ARIES systems code & VASST
Document error corrections & modifications to the systems code

- Mod #, date,
- Error correction or modification
- Lines of code affected
- Person responsible for input
- Status - complete, in progress, or pending
- Notes
Revision control is necessary and helpful

- Must track and control revisions to the code.
- Subversion (SVN) software maintains the code centralized in a server repository.
The database chronicle contains important details

- What input parameters were scanned?
- What version of the systems code was used? Any changes? Version #
- What blanket/divertor were implemented?
- What were the assumptions applied in the code?
- What filters were implemented? (Pnetel, Qdiv, B, etc.)
- What costing algorithms were used, year\$, material properties?

⇒ Every result/picture/graph must be traceable and backed up with specifics of its origin

<table>
<thead>
<tr>
<th>Database Chronicle</th>
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<tbody>
<tr>
<td>Log #</td>
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<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
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<td>15</td>
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Summary

✓ New VASST visualization tool provides visual interaction with systems code database and gains insight into design tradeoffs.

✓ Utilized VASST to help define preliminary strawmen for ARIES Physics & Technology Assessment.

✓ Continuing chronicle and documentation of systems code

✓ Thicken database to encompass 4-corners design space to issue refined strawmen for detailed design.