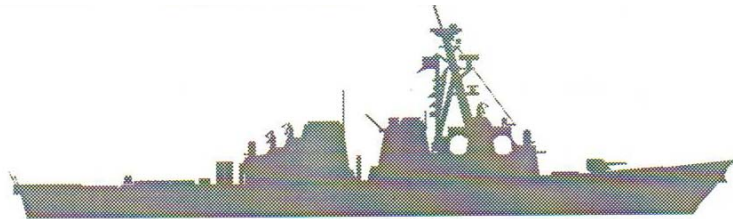


*Phased Array Radar . .  
and the AEGIS system  
. . a historical perspective*



USS TICONDEROGA CLASS CRUISERS



USS ARLEIGH BURKE CLASS DESTROYERS

an informal talk about experiences  
and engineering challenges in this  
most interesting development

Robert T. Hill  
Radar Lecturer  
USA

# *Here's what we'll talk about*

. . a little Aegis history . .

. . answering the skeptics questions . .

. . going “from paper to practice” . .

. . “System Engineering”, then . . today . .

*All with a view toward “Lessons Learned” - technical AND managerial*

## *. . a little Aegis history . .*

1958 . . assessment of present systems

1963 . . first stated requirement by our navy

1964 . . “Proposed Technical Approach” issued

1965 . . “ASMS” Assessment Group (Industry, Government)

1966

- 1967 Army/Navy commonality issue (one development?)

1968

- 1969 “Contract Definition” (industry – funded, competitive)

1970 . . development awarded (RCA)

*and then the fun began!*

Mid 1970s, 1980s . . full production, US Cruisers, Destroyers

## The 1960's

Redefining the “scope” of procurement . . system-wide  
role of a prime contractor and his team . .  
organization within the procuring agency

Establishing the whole-system “architecture”

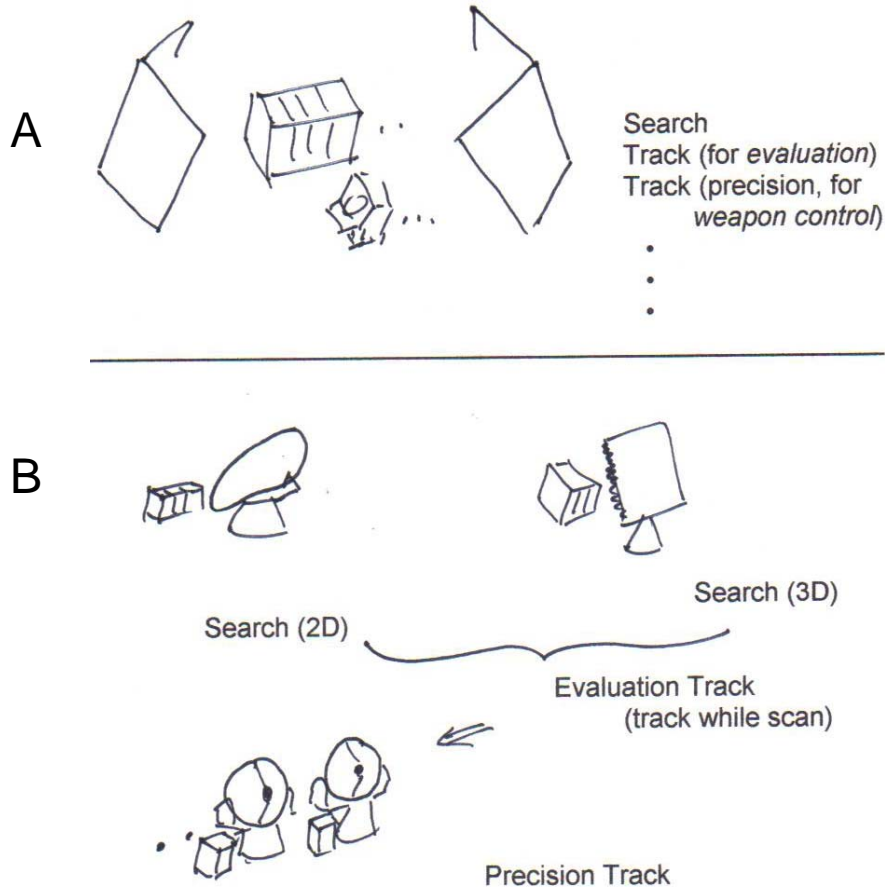
The rally of laboratories, industry and government . .  
. . teamwork in establishing “feasibility” (obligatory)

The nature of the first “specifications”, of the  
“statement of work”, of the “request for proposals”

*things fixed, things illustrative*

*things operational, things “metric”*

. . about the “architecture” (the very nature of the system)



“New” requirements  
of  
reaction time  
and  
capacity

said “A” . .

. . and *it* developed  
*with* the rest of the  
combat system!

. . *then came many questions . .*

“How does this (phased array) work?”

“How will I *know* it’s forming a beam?”

“Why S-band?”

“What about the ‘handover’ (array to array) problem?”

“How can you get *precision* track on  
so many targets at once?”

“Why such *long* search ‘frame times’?”

. . just a comment here, on each . .

Lesson: no wonder I became a  
*teacher* of radar!!

. . still in the 60s . . about that “Army/Navy commonality” issue . .

. . can’t the two services have just *one* development and share the system?



Answer . . involves the “Bern tunnel requirement”,  
and illustrates both an important *radar* principle  
and an IMPORTANT ENGINEERING PRINCIPLE!

. . about those early specifications

VERY modest (by *today's* standards)  
in radar techniques, performance

*we knew we were in  
“uncharted” waters . .*

Having to explain the NATURE of specifications:

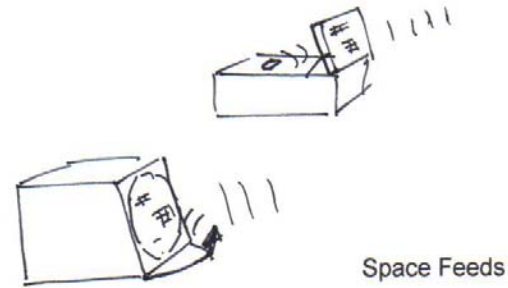
An operational, or performance, spec  
A “metric” spec

*we knew we were going  
to build and test this radar . .*

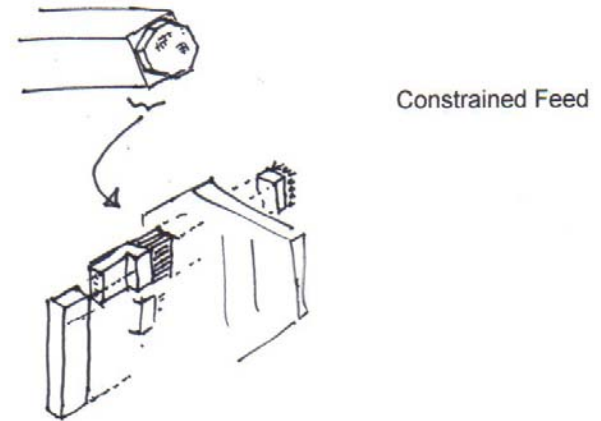
. . specifications . .

## The Choice of Feed Types . .

Space (or “optical”) Feeds  
Feedthrough (“lens”)  
Reflect-array



Constrained Feeds  
Microwave routing,  
beamforming networks  
behind the array face



In our case –  
constrained feed necessary:  
physical strength  
slab-like form  
illumination function control

. . specifications . .

## The Phase Shifter Choice

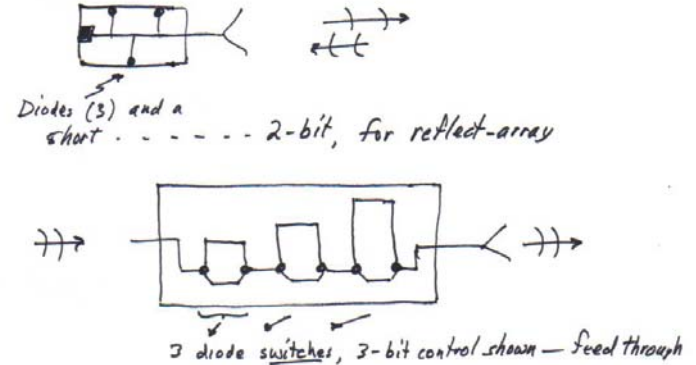
Diode types  
for the reflect-array  
for feedthrough  
(of either feed type)

- ➔ Ferrite types
  - reciprocal non-latching  
(Faraday rotators)
  - non-reciprocal latching
    - multiple core, saturating
    - single core, major AND  
minor hysteresis loops

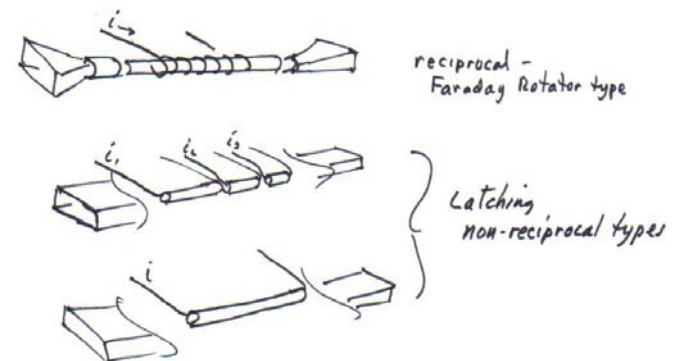
Much lab work (1960s) . . insertion loss < 1 dB the goal;  
impedance matching techniques, fairly broad band;

- ➔ ferrite materials: cost and temperature sensitivity concerns

### Diode Phase Shifters



### Ferrite Phase Shifters



. . specifications . .

About array placement . .

. . and avoiding “specification-peaked” design

About the transmitter . .

. . tube choice . . and the *desire* for

“rf modulation” dc-operated tubes

( . . and the subsequent abandonment)

About the initial signal processing . . commitment

to *digital* signal processing (pulse compression)

. . and the *evolution* of it, early on!

About multifunction radar *control* and *interface*

*. . from "paper to practice" . .*

About the transmitter

critical item, tube development . . and our testing of tubes

we need modulators after all . . final tube choice

handling heat: "it's raining in the transmitter cabinet"

About the array

cooling the array . . and the phase-shifter choice

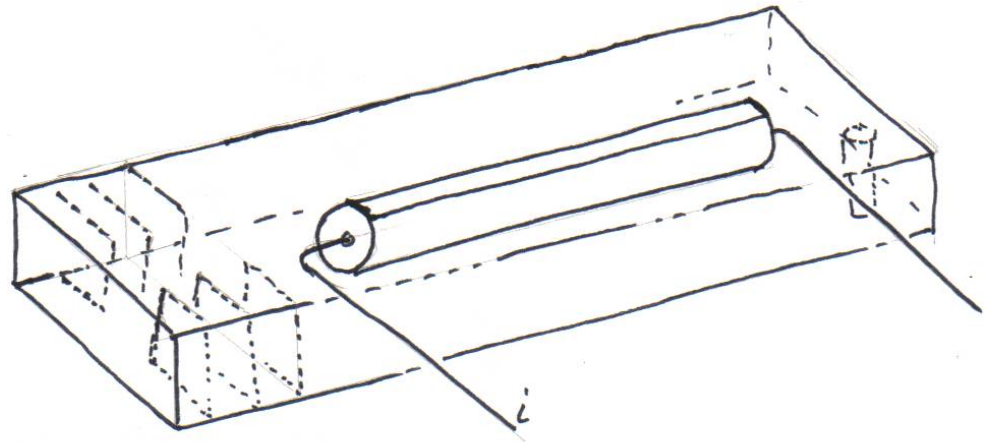
and that phase shifter cost matter →

array reliability . . a *cautionary* tale, or two . . →

the development testing of the array . . →

*Paper to practice . .*

What irony!



Paper Design?

Materials studied,  
refined; great concern  
about that material's  
cost

Production?

Process very  
labor intensive  
Test (vswr) and adjust  
*while fabricate*  
Test, *inspect and*  
approve each one!

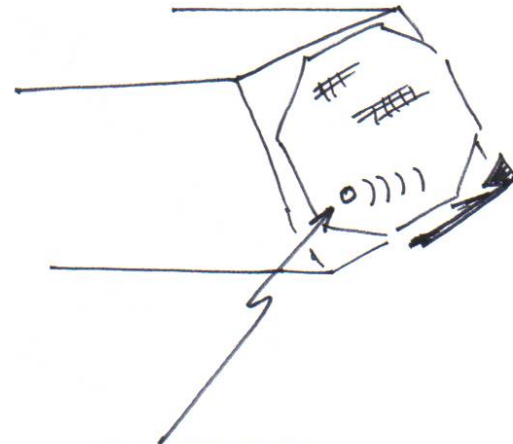
Material cost proved  
almost insignificant !

now, the "cautionary" tale . .  
 . . about phased array reliability

We've all heard the claim,  
 a popular refrain:

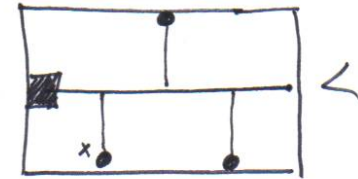
" . . as many as 10% of the  
 elements can fail with  
 very little consequence . . "

Failure *nature* can be far different  
 than simply a few elements not  
 radiating . .



Our early experimental  
 "reflect-array" at NRL . .  
 1964 or so . . with its  
 monopulse feed

One element failed  
 = total system failure



$$\left. \begin{aligned} V_{bias} + V_{rf} &> V_{initiate} \\ V_{bias} &> V_{sustain} \end{aligned} \right\}$$

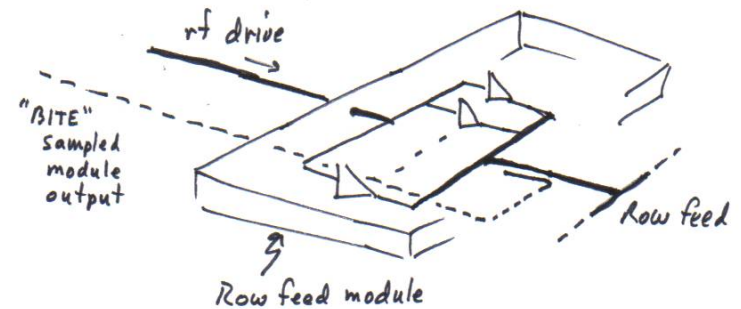
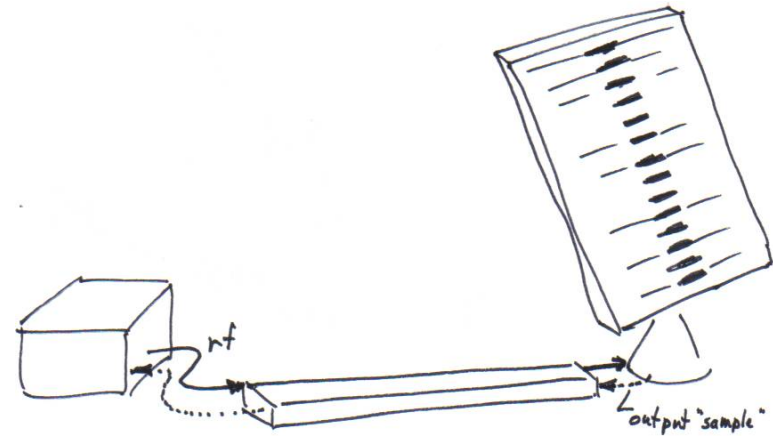
in a tiny "carbonized" path  
 around the diode junction

Interfering noise source during reception period  
 only if transmitter was on (to *initiate* the discharge)!

*.. and a second example of  
"extraordinary" array failure*

*(during development testing  
in a program other than  
our own .. I was asked to  
"investigate" this happening).*

The point of these "tales" is that some single, more "orderly" failure may well be more likely than just the random loss of radiation at the element level.

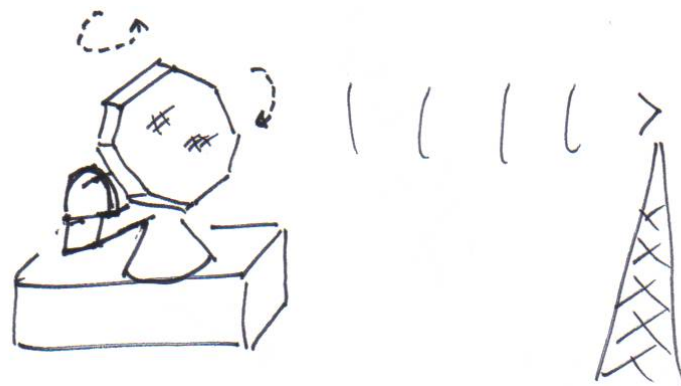


Experimental Configuration . .  
.. longer than intended  
cable trough!!

. . on the array testing . .

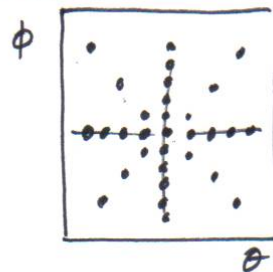
. . oh, did we want  
to see *patterns*!!

. . contractor's point  
very well taken . . and  
we cut back considerably  
on the "sampling" we  
had called for!



Array Testing, Development

Our plan:

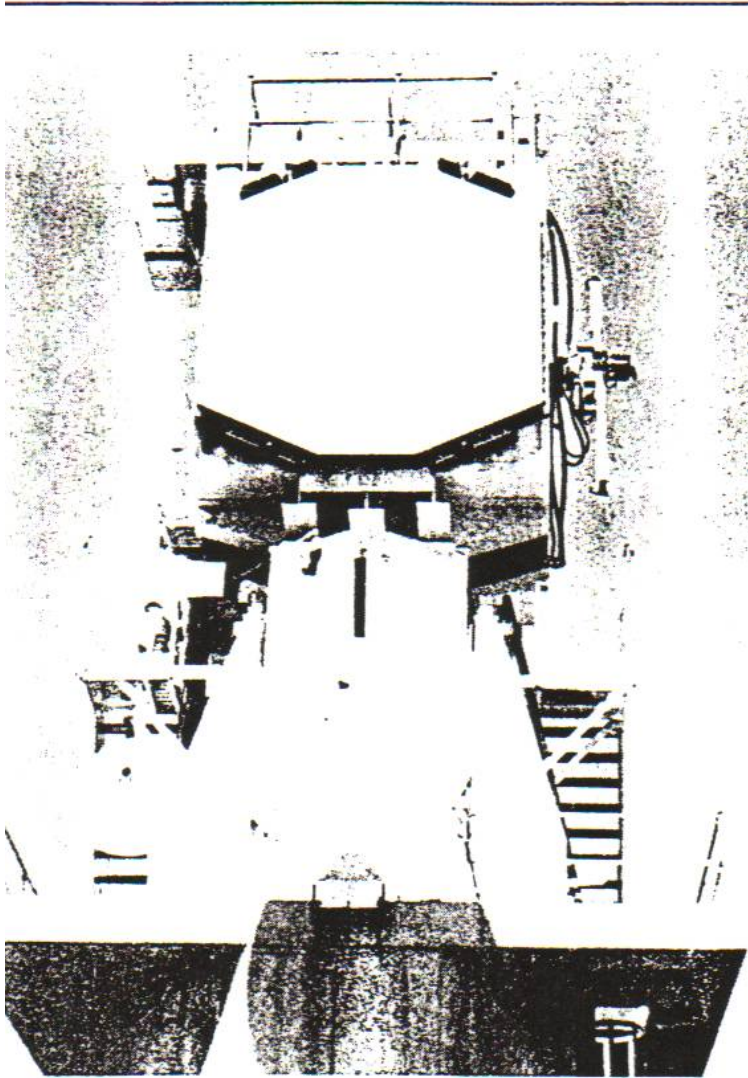


at  $f(1,10)$   
raster scans at  
 $\frac{1}{4}^\circ$  and  $\frac{1}{2}^\circ$  steps  
over  $20^\circ \times 20^\circ$  over  $90^\circ \times 90^\circ$   
 $\Sigma, \Delta, \Delta$  !!

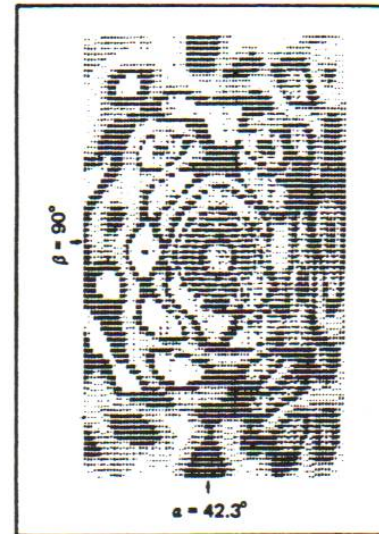
TOO MUCH!!

Array Testing, Production

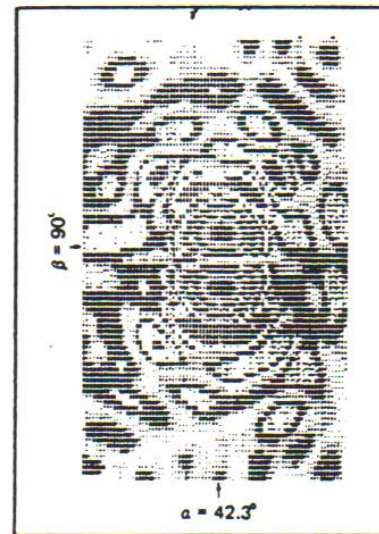
Use of Near-Field measurements at a  
chamber right on the production line!



/SPY-1 Array on Test Positioner.



Pattern, Monopulse Sum.

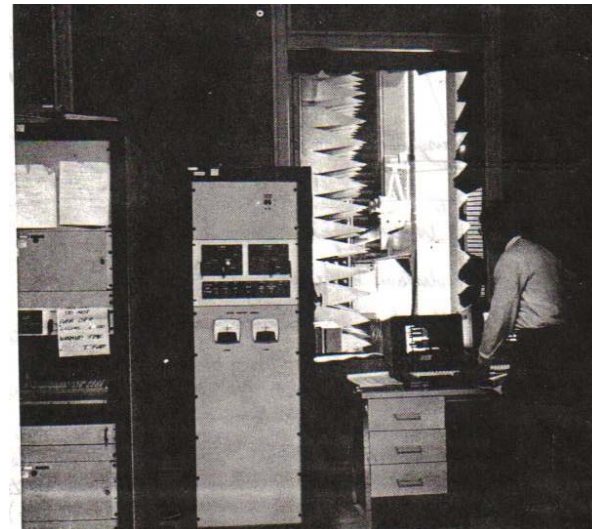
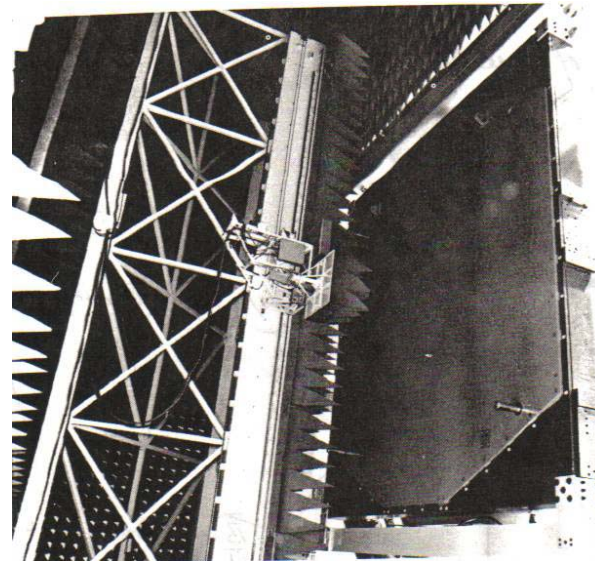


Pattern, Monopulse Elevation Difi

. . and, of course, we recognized in the process of such *development* testing that we would have to go to near-field antenna measurements in *acceptance* testing in the forthcoming production of the system, quite new at the time.

Lesson – these early experiences helped us consider and define the three categories of testing in such an acquisition:

- Development tests
- Acceptance testing in production
- Field testing in deployment



About the automation of such radar,  
its “own” data processing and control

the “video-formatter” nonsense

a misunderstanding about “computer programs”  
and what’s really involved in control logic

the essential “dotted line” effort, maintaining  
functional currency during a *long*  
development

just a few remarks here

# *System Engineering . . then . . today*

## Our experience in Configuration Management

- a progressive design control process is *vital* during development, of course
- however, we never permitted use of the colloquial term “design freeze”
- in a protracted program, the need to resist classical “standardization”
- an irony in the computer program area . . I’ll mention

# *System Engineering*

*and the need to continually appraise all the elements  
of the system . . . and re-allocate performance as required*

I'll comment on two illustrations of this principle:

- our underestimating the significance of  
unprecedented “fast reaction” in such a system
- having to reconsider the radar's uplink commands

# *System Engineering*

*and the need for progressive integration and test facilities*

Earliest full scale mockup . . the physical equipment

. . became the LBTS, Land-Based Test Site

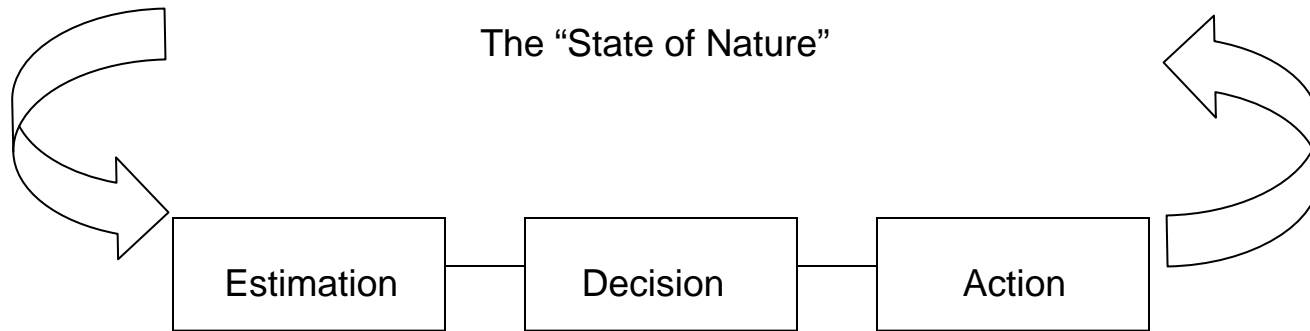
. . moved (single-faced radar; other elements)  
to the early test ship – only after a system-wide  
“fast cruise” at LBTS

. . LBTS became the larger CSEDS, combat system  
engineering development site (ship’s superstructure  
and all, in the middle of New Jersey!)

. . CSEDS becomes the Production Test Center  
and AEGIS Training Site

# System Engineering

*and the need to keep focus on the whole system  
(someone must keep his attention "elevated"  
.. certainly the project manager!!)*



A "closed" system: an assembly of means by which a sensed state of nature is altered, or one's relationship to the state is altered, to make the state or the relationship more desirable.

.. and my little story about this simple diagram will end our discussion ..

*It was a great development . .  
still being built upon, staying current . .  
and a great personal experience*

*Thanks for letting me talk about it!!*

*Good luck in all you do in similar engineering!*