Boeing Defense, Space & Security
PhantomWorks

Distributed Computing in ModelCenter Using Cloud-based Virtual Machines

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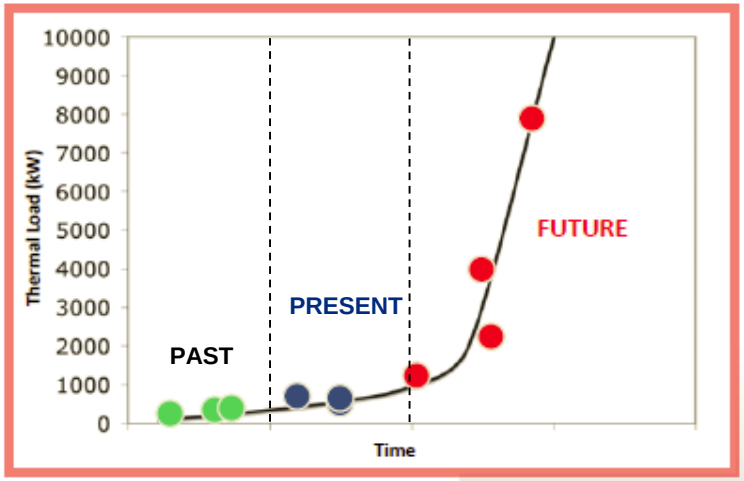
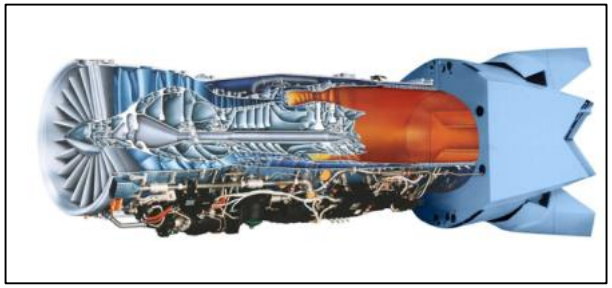
Advanced Aircraft Subsystem Design Challenges

- **Increased mission power**
- **Increased flight speeds**
- **Increased survivability**
- **Increased engine performance**



Expect a 10x to 100x increase in power and thermal system capacity



System design and integration challenges are increasing significantly for future advanced aircraft and must be accounted for in the design process

OPTIMUS Overview

OPTIMUS Need

Gaps Exist In Tools To Perform:

- **Vehicle MDAO With Subsystem Effects**
- **Subsystem/Propulsion Interactions within Conceptual Design Space Exploration**

Flight-Centric MDAO

+

Subsystems

=

+

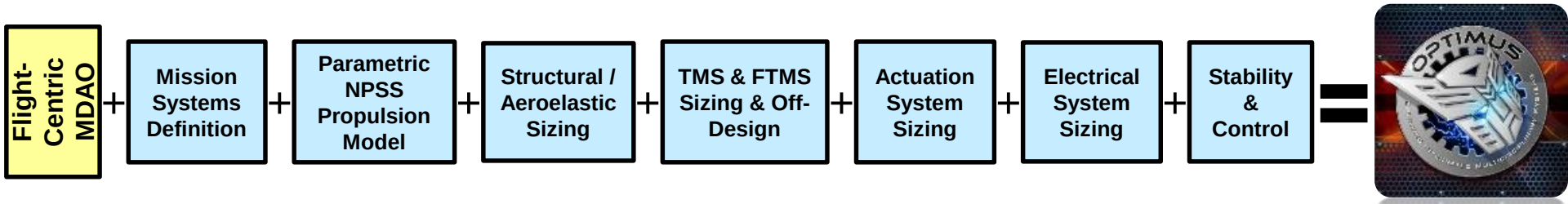
Parametric Engine

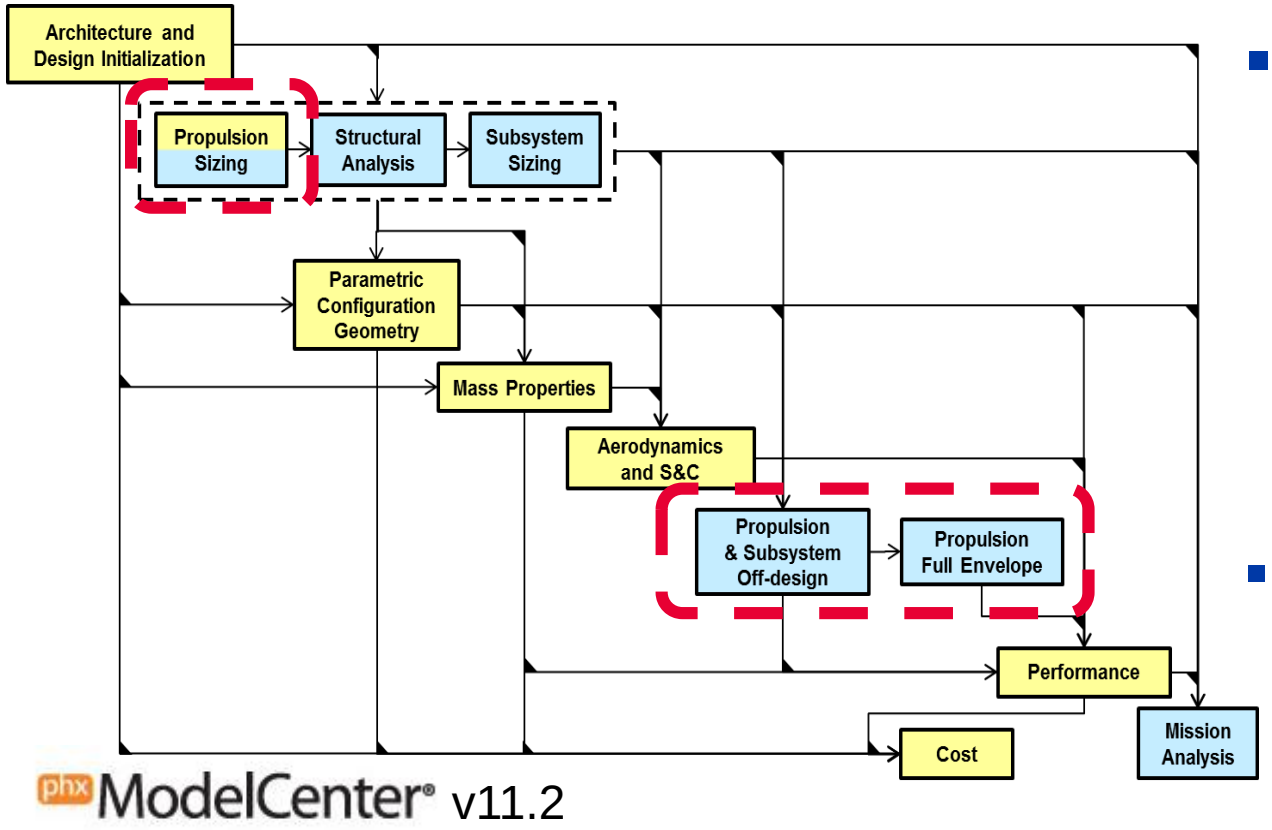
OPTIMUS Program Objectives

- **Objective #1: Expansion Of A Multi-Disciplinary Optimization (MDO) Based Design Process**
  - Take Into Account & Assess Advanced Technologies In The Area Of Power, Thermal, Propulsion (From Inlet To Nozzle), Energy Storage, & Actuation "Systems" Early In The Multidisciplinary Design Process
- **Objective #2: Integration Of Operations Analysis To Allow Mission Effectiveness Measures To Drive The Vehicle Design**
- **Objective #3: Demonstration Of Real Time Geographically Distributed Architecture To Virtually Connect Different Design Groups**
- **Objective #4: Application Of The MDO Process Developed In The First Three Objectives To An Air Superiority Aircraft Suitable For Application In A 2030 Anti-Access/Area-Denial Environment**

OPTIMUS Brings Physics-Based Analysis Into The Conceptual Design Phase To Help Prevent The Late Discovery of Defects On Programs

OPTIMUS MDAO Architecture

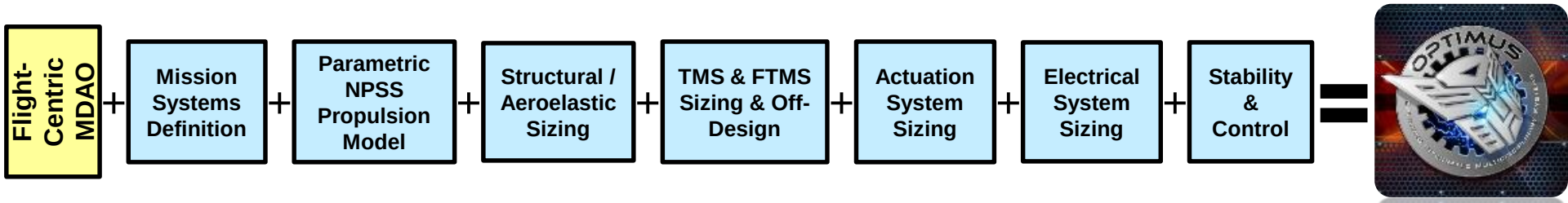




- **OPTIMUS 2-3x more complex than Flight - Centric work flow**
  - ~3x number of linked applications
  - ~2x number of links
  - ~3x number of variables
- **Run time per case**
  - OPTIMUS: ~80 mins
  - Flight-Centric: ~ 5 mins

Computation time increased 20x over Flight-Centric model!

OPTIMUS MDAO Architecture



500 Case Design of Experiments

X

80 minutes per case

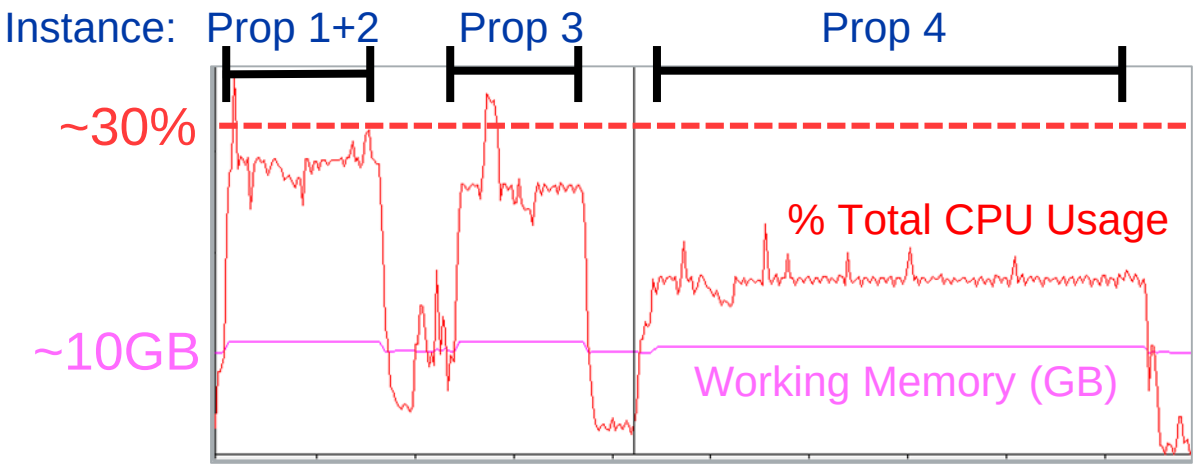
= 28 Days!!!

phx ModelCenter® v11.2

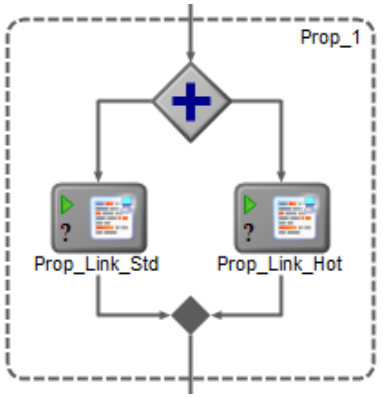
Computation time increased 20x over Flight-Centric model!

Model Bottleneck: Propulsion

- **Long pole and CPU hog: Boeing installed propulsion code + parametric NPSS engine model**
  - Single case test performed on a stand-alone "Tech" PC
    - ModelCenter 11.2, 24 GB RAM, 12 Hyper-threaded Cores, Windows 7



Propulsion Instance	% Total Run Time
1	17%
2	11%
3	11%
4	52%
Prop Total	**90%**

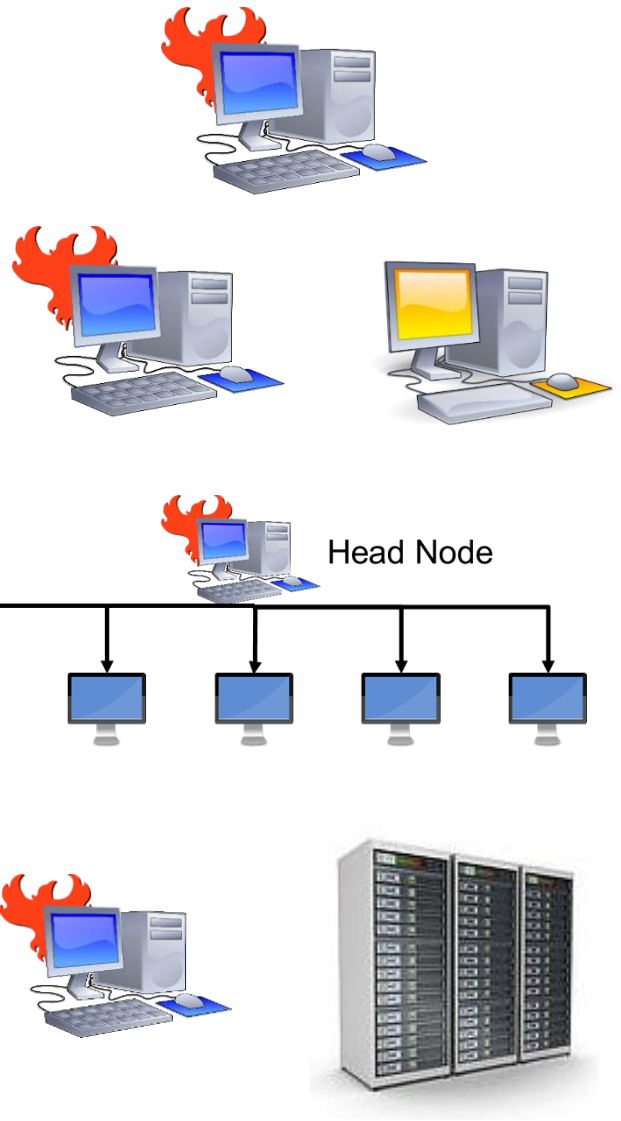


- **Parallel propulsion CPU requirements quickly maxed out cores on a "Tech" PC**
- **Maximum 2-3 parallel instances using ModelCenter load balancing**

Must explore other parallelization options for Propulsion!

Parallelization Options

- **Internal ModelCenter load balancing**
  - Allows ~2 parallel runs (40 mins/case)
- **Distributed computing using "Tech" PCs**
  - Analysis Server distributes Prop runs with wrappers
  - Allows ~4 parallel runs (20 mins/case)
  - Only 1 additional "Tech" PCs available
- **Distributed computing using cloud-based virtual machines (VMs)**
  - 5 virtual machines could be requisitioned on demand
  - Analysis Server distributes Prop runs with wrappers
  - Allows 5 - 10 parallel cases (8-16 mins/case)
    - Possibly more with ModelCenter 12
- **High Performance Computing (HPC) clusters**
  - Many integration questions with legacy codes
  - Possibly high program cost
  - Could allow >> 10 parallel cases



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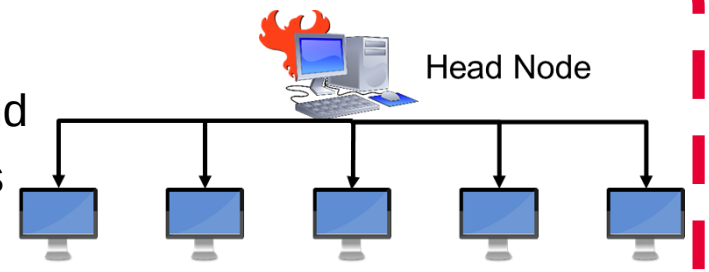

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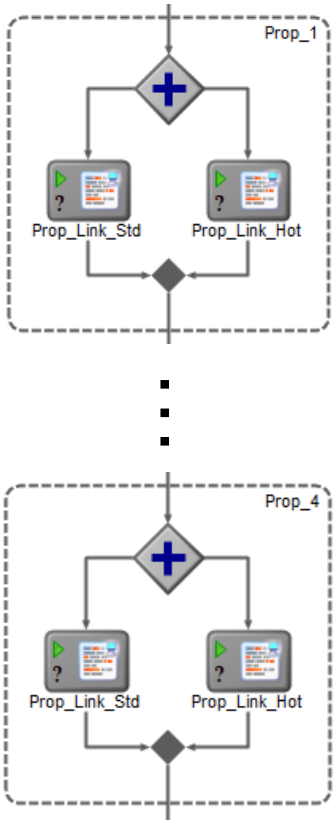
Cloud-based Virtual Machines

- **Virtual Machines (VMs) are software computers that imitate actual physical computers**
  - Ideal sandbox environments for testing new software
- **VMs can be automatically provisioned from Boeing computing clusters on-demand**
  - VM specifications match or exceed standalone “Tech” PCs
  - VMs meet ITAR restrictions
  - VMs can act as on-demand computing power for MDAO studies
  - No cost to program
- **Batch scripts developed to automate VM setup process**
  - 5 VMs ready for distributed propulsion runs in ~3 hours

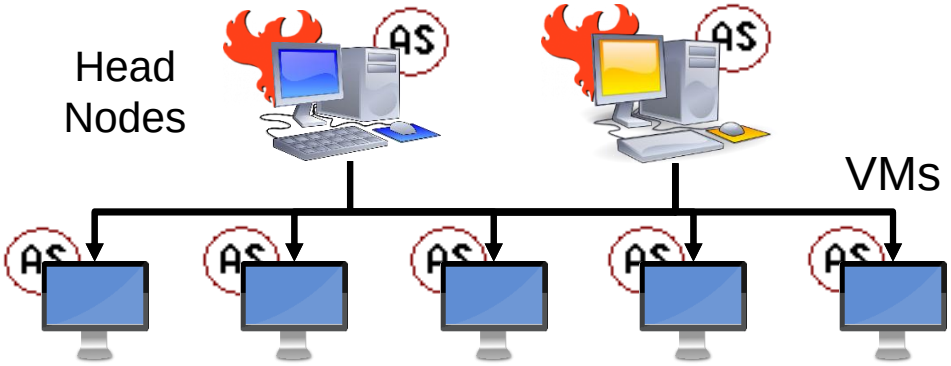
VMs give computing muscle for OPTIMUS parallelization

Parallelization Setup

- **Analysis Server enables communication between head nodes and virtual machines**
  - Run Analysis Server on each VM and head node
  - Use .link file in workflow (replaces .scriptWrapper) to point to Propulsion scriptWrapper on VM
    - Each VM runs Propulsion locally
  - Set trade study load balancing to run with 5 local copies and enable RunShare mode in all wrappers
  - Analysis Server round robin load balancing distributes runs to VMs as the workflow requests them
- **Two head nodes running ModelCenter sessions and data sets were utilized to more fully exploit VM resources**



Parallel Prop wrapper setup



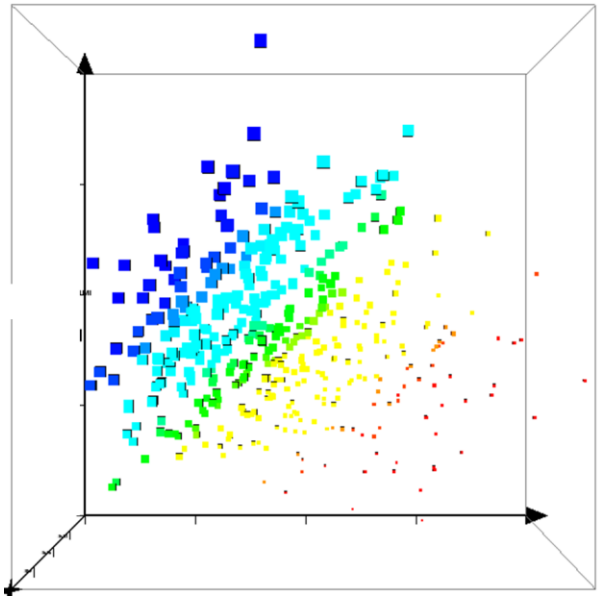

```
type: redirect
aserv://vm_hostName1/wrapFolder/npssWrapName
aserv://vm_hostName2/wrapFolder/npssWrapName
aserv://vm_hostName3/wrapFolder/npssWrapName
aserv://vm_hostName4/wrapFolder/npssWrapName
aserv://vm_hostName5/wrapFolder/npssWrapName
```

Example link file

Results

- **Average effective case run time with VM parallelization**
  - 11 minutes
- **Shorter run time enables large Design of Experiments (DoEs) and multi-objective optimizations**
  - 500 case DoE run time = 4 days
  - Multi-objective optimization run time = 1 week
- **All results for OPTIMUS program generated using this parallelization scheme**
  - ~ 4000 DoE points
  - ~ 2000 optimization runs on truth model
  - Total: ~45 days of run time

		Model Run Time (mins)	
Computer Resources	**Parallel Runs**	Case Avg.	Case Avg. /Parallel Instance
1 HN, 1 Sec	2	68	34
1 HN, 1 Sec	4	86	21
1 HN, 5 VMS	5	89	18
2 HN, 5 VMS	***10***	***110***	***11***



OPTIMUS Modeling Lessons Learned

- **MDAO developers need to be involved in analysis code development as early as possible**
- **Run time should be assessed and parallelization plan drafted early on in development process**
  - 32-bit ModelCenter has trouble parallelizing OPTIMUS level workflows
  - 64-bit ModelCenter should mitigate memory issues
  - More features for easier large scale distributed computing would be better
- **COTS tools with plugins are double-edged swords**
  - Expediency vs run time and computer resources
- **Large variable count and model complexity necessitates standard, general, and clear naming convention**
  - Must include units!
  - ModelCenter needs to accommodate long descriptive names
- **ModelCenter RSM fitting and validation options and memory management could use improvement**

Summary and Future Thoughts

- **Summary**
  - OPTIMUS program built an MDAO model to address gaps in the future advanced fighter design process
  - Due to long run times, cloud-based VM assisted parallelization was implemented to enable running of large DoEs and optimizations
  - ModelCenter & Analysis Server facilitated this parallelization through easy to implement load balancing and analysis distribution across a network
- **Future thoughts**
  - Work must be done to decrease model run time to enable more time efficient MDAO trade studies
    - HPC or larger scale distributed computing necessary for certain MDAO software
  - VM setup and usage could be expanded for on-demand MDAO services (scalability)
  - Re-doing OPTIMUS runs with ModelCenter 12.0 could allow for shorter run time using presented VM approach

Acknowledgement

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