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Topics in Development of Naval Architecture Software Applications

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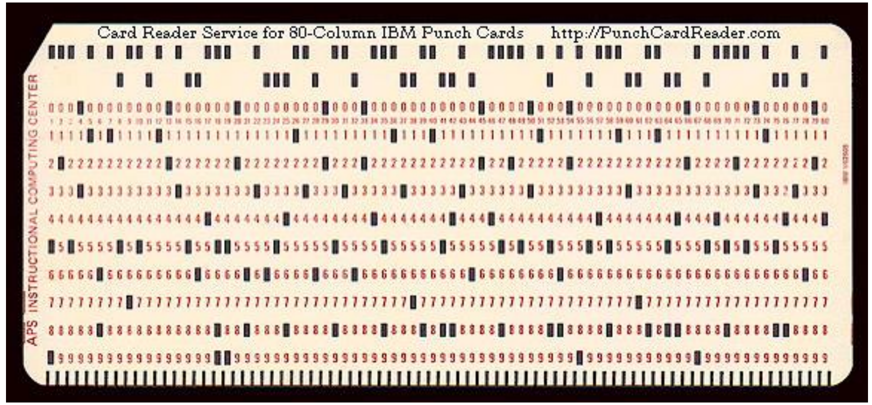
Naval Architecture Software Applications - Outline

- Evolution of naval architecture software
- What's happening today: great complexity
- How we work as a team to develop software
- Where are we going?

Early Days

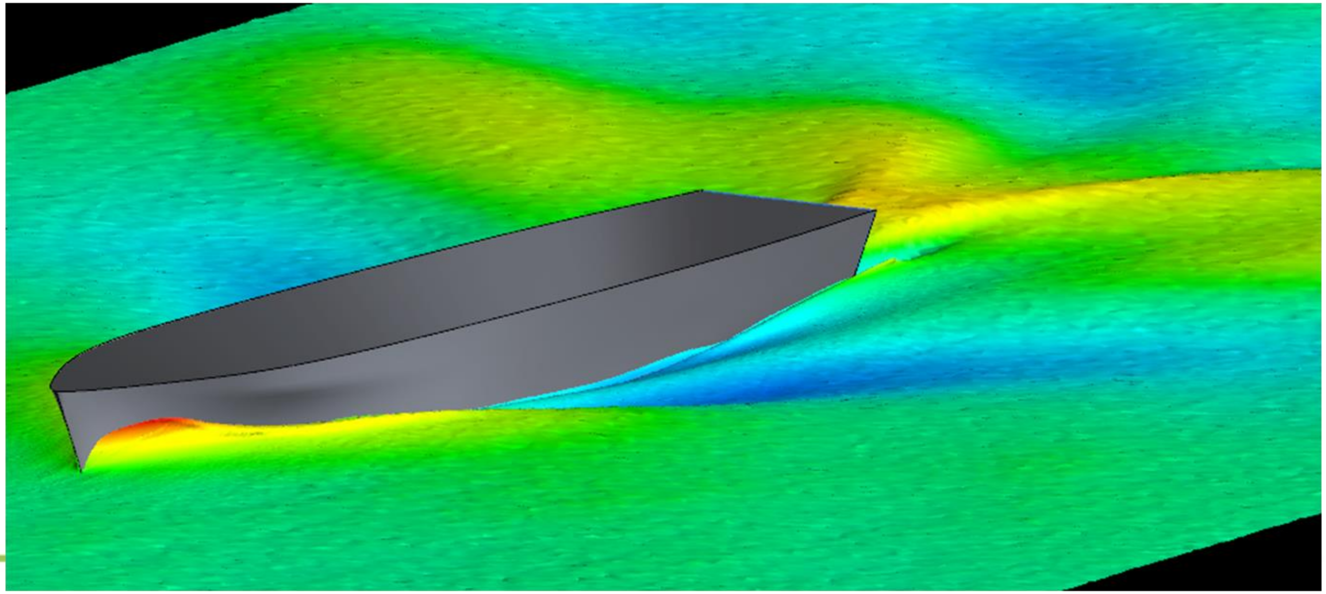

Card Reader Service for 80-Column IBM Punch Cards
http://PunchCardReader.com
APS INSTRUCTIONAL COMPUTING CENTER

Evolution of Naval Architecture Software Applications: Early software applications (1960s and 1970s)

- Hydrodynamic added mass and damping for arbitrary two-dimensional hull sections (Frank 1967)
- Ship hydrostatic analysis (Naval Ship Engineering Center 1976)
- Basic ship structural optimization (Hughes and Mistree 1976)
- Definition of hull lines using splines (Fuller, Aughey, Billingsley 1977)
- Estimation of ship performance properties using regression of experimental results:
  - Powering (Holtrop and Mennen 1978)
  - Maneuvering (Inoue, Hirano, and Kijima 1981)

Evolution of Naval Architecture Software Applications: Contemporary applications

- Prediction of ship resistance with computational fluid dynamics, including detailed modelling of viscous effects (Thornhill 2008)
- Simulation of ship maneuvering in waves (McTaggart 2010)
- Simulation of large-magnitude ship structural deformation, including collisions (Haris and Amdahl 2013)

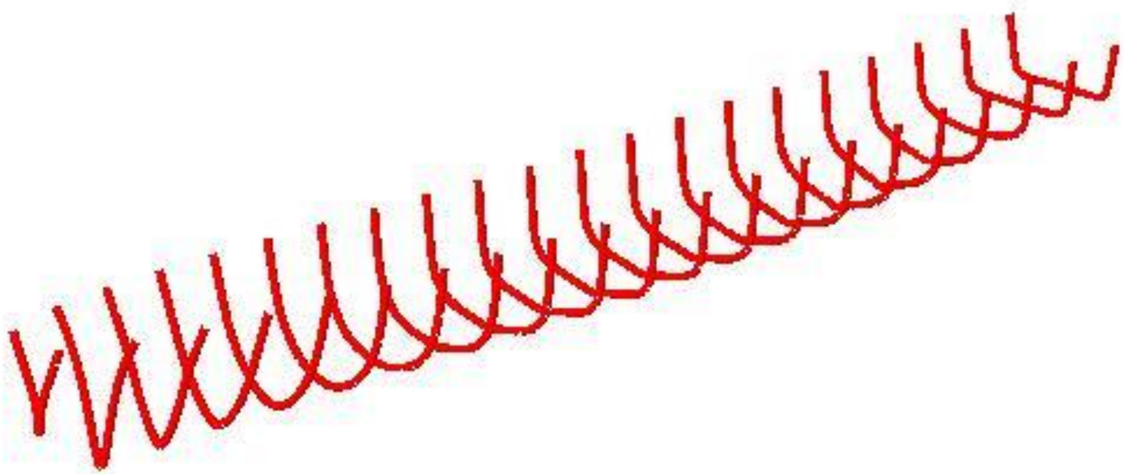


Evolution of Naval Architecture Software Applications: Increasing Complexity

	1988	2013
Languages	Fortran	C++, C#, Java, Python, …
Lines of code	5,000	5,000,000
Size of development team	1-2	5-10
User input method	Text file or console line	Graphical user interface
Seakeeping prediction	Strip theory, frequency domain	Strip theory or 3D, frequency domain or time domain
Resistance prediction	Potential flow	Viscous flow
Structural analysis	Hull girder	3D finite element

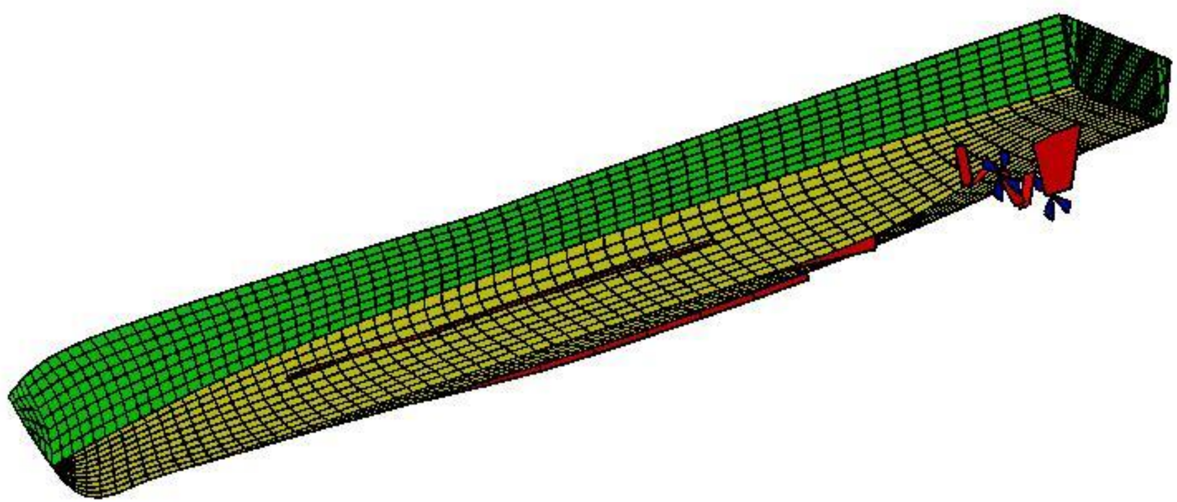
Example Contemporary Applications: Frequency Domain Seakeeping with Strip Theory

- Salvesen, Tuck, and Faltinsen (1970) give excellent overview
- Assumes ship geometry is slender:
  - Applicable for most naval vessels
- Surprisingly good results when compared with more sophisticated approaches



Ship Motions Prediction with 3D Models

- 3D theory gives advantages over strip theory:
  - Applicable to wider range of hull forms
  - More accurate sea load predictions
  - Modelling of interaction effects between vessels
- Small computational times on modern desktop computers

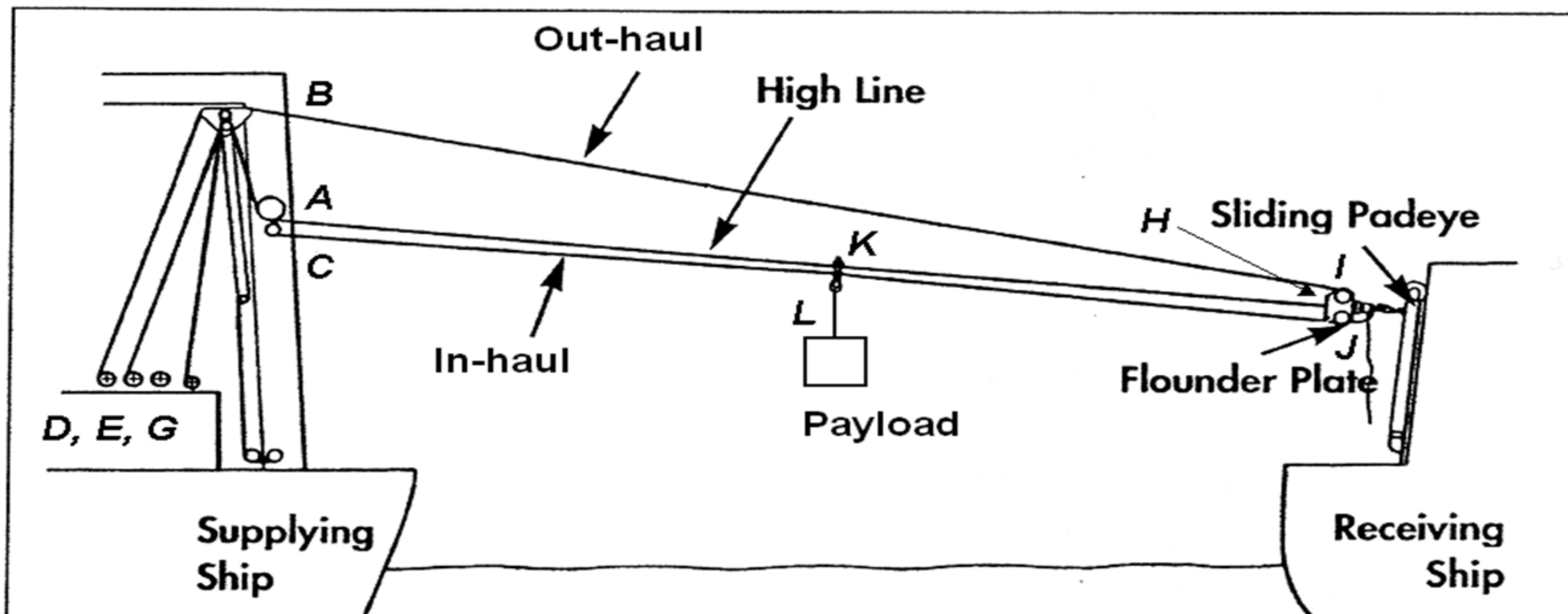


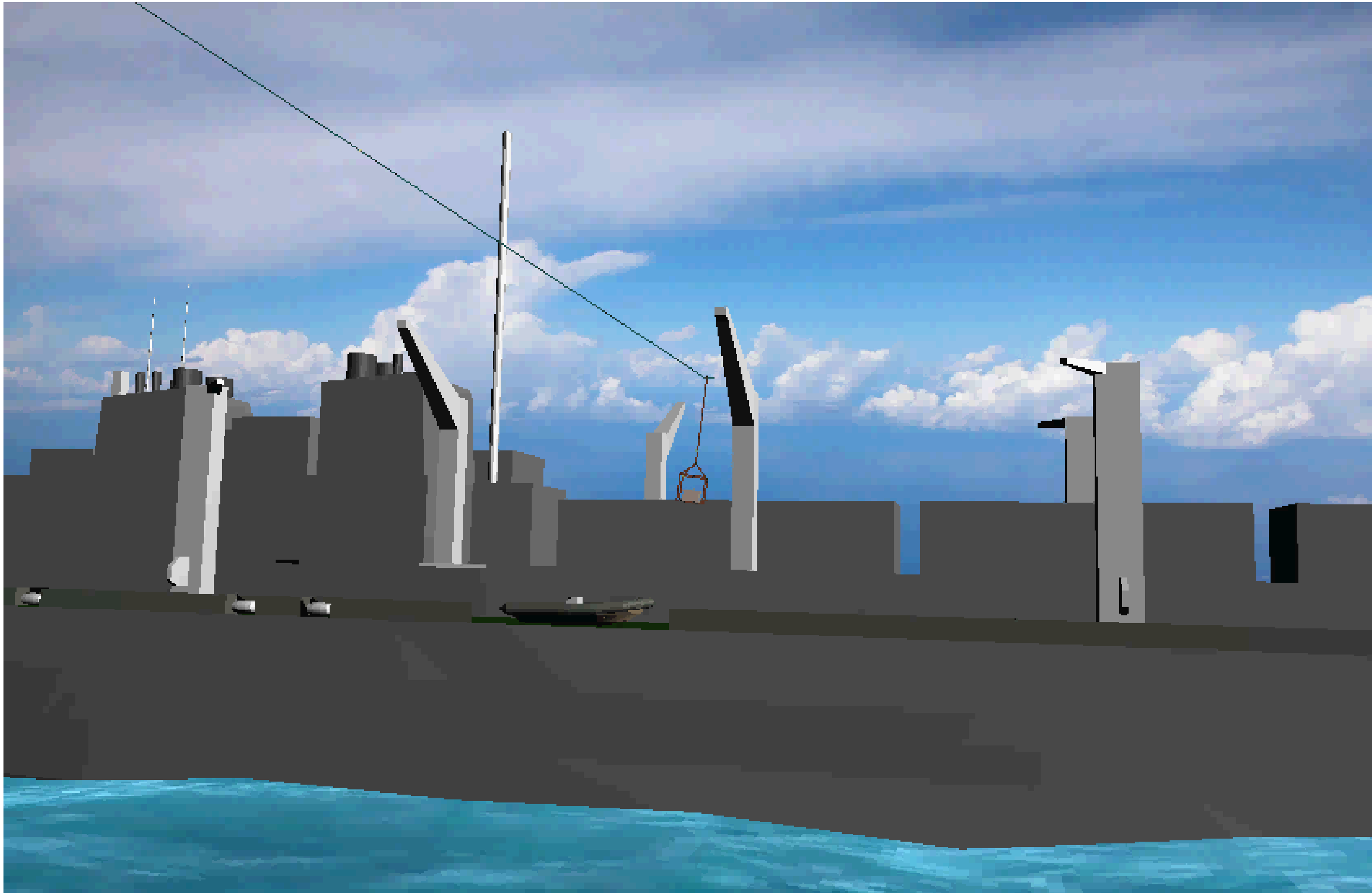
Simulation of Ship Motions in the Time Domain

- Time domain simulation presents new opportunities
  - Maneuvering
  - Nonlinear forces
  - Interoperability with other simulations
- Can often run in real-time or faster

Example Contemporary Applications: Simulation of Replenishment at Sea

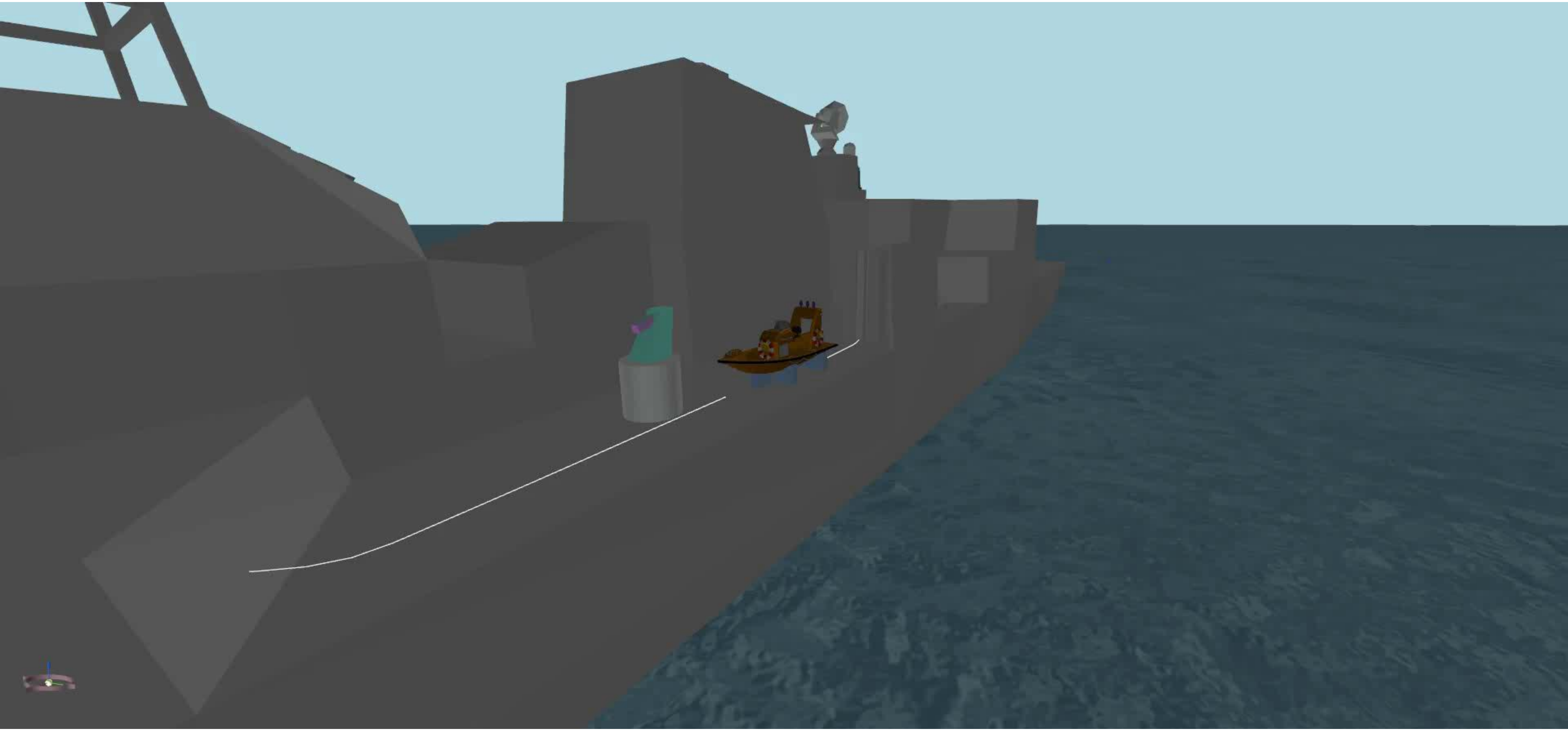
- Seaway
- Supply ship, including helm and motions in seaway
- Receiving ship, including helm and motions in seaway
- Replenishment gear





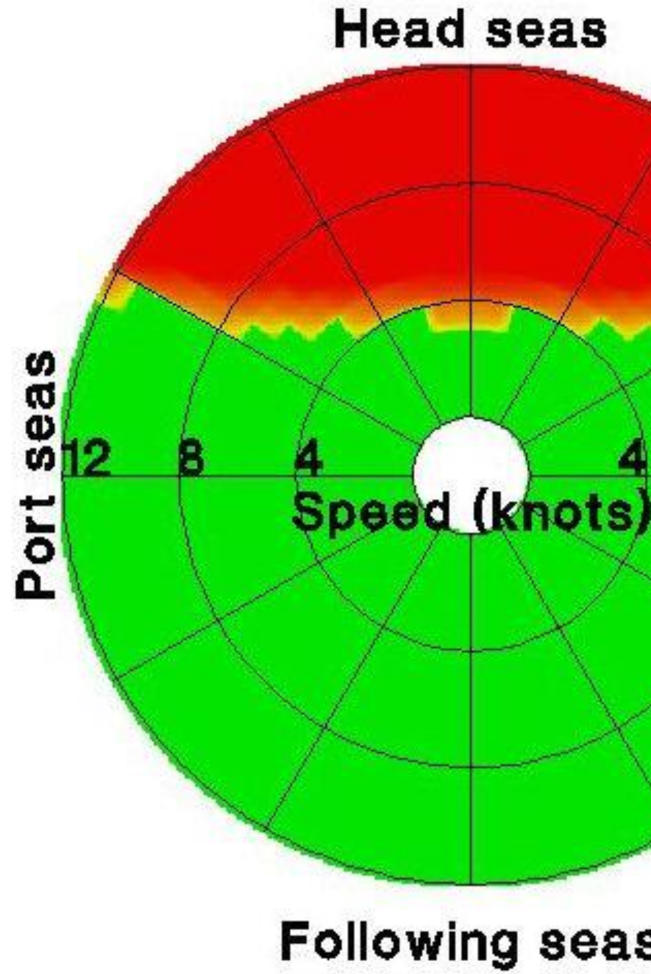
Example Contemporary Applications: Simulation of Launch and Recovery of Small Boats from Ships

- Navies have great interest in launch and recovery
  - Anti-piracy
  - Search and rescue
  - Autonomous vehicles
- Launch and recovery becomes increasingly challenging as sea state increases



Ship Operator Guidance

- Can provide real-time guidance
- Seaway measurement
- Rapid computation of ship motions
- Very enthusiastic response from ship operators



Where Are We Today?

- Software is very complex
- Huge range of skills required
- No single person can complete work

How Do We Get the Job Done?

- We use modern software technologies
- We work as a team

Relevant Technologies for Modern Software Development

- Spoilt for choice
- Must consider both initial development and long-term maintainability of software

Wide Availability of Programming Libraries

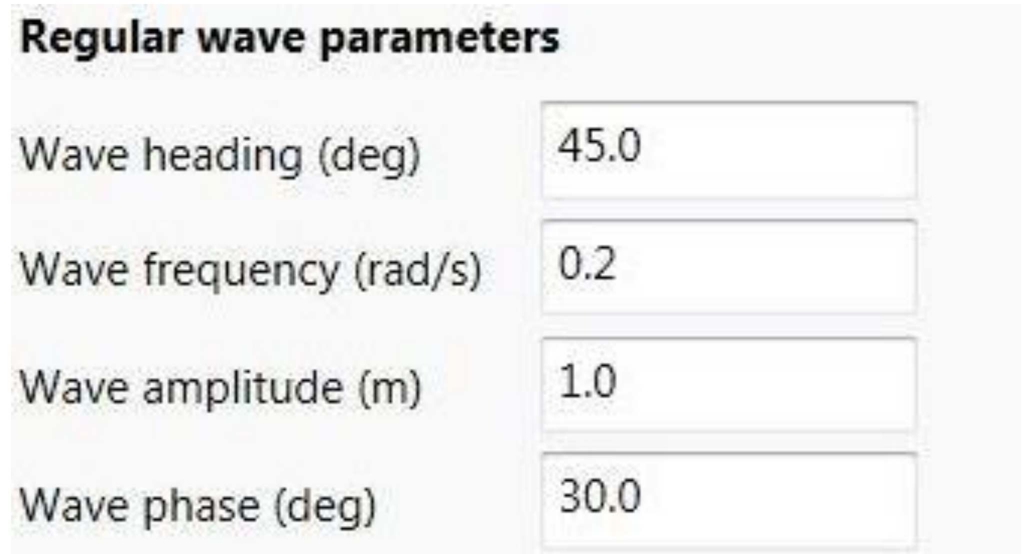
- Usage of existing software libraries can bring many advantages:
    - Reduction of development effort
    - Existing documentation
    - Existing expertise using software library
- Be aware of licensing terms:
    - No cost or restrictions
    - No cost but restrictions on developed software
    - Cost for developer license ($)
    - Cost for developer license and for runtime license ($$)

Object-Oriented Programming

- Dominant approach for developing modern software
- C++, C#, Java, etc.
- Example objects from ship motion library:
  - Seaway
    - RegularSeaway
    - MultiComponentSeaway
  - ShipHull
    - DryShipHull
    - WetShipHull
  - ShipAppendage
    - Rudder
    - Bilge keel

Graphical User Interfaces

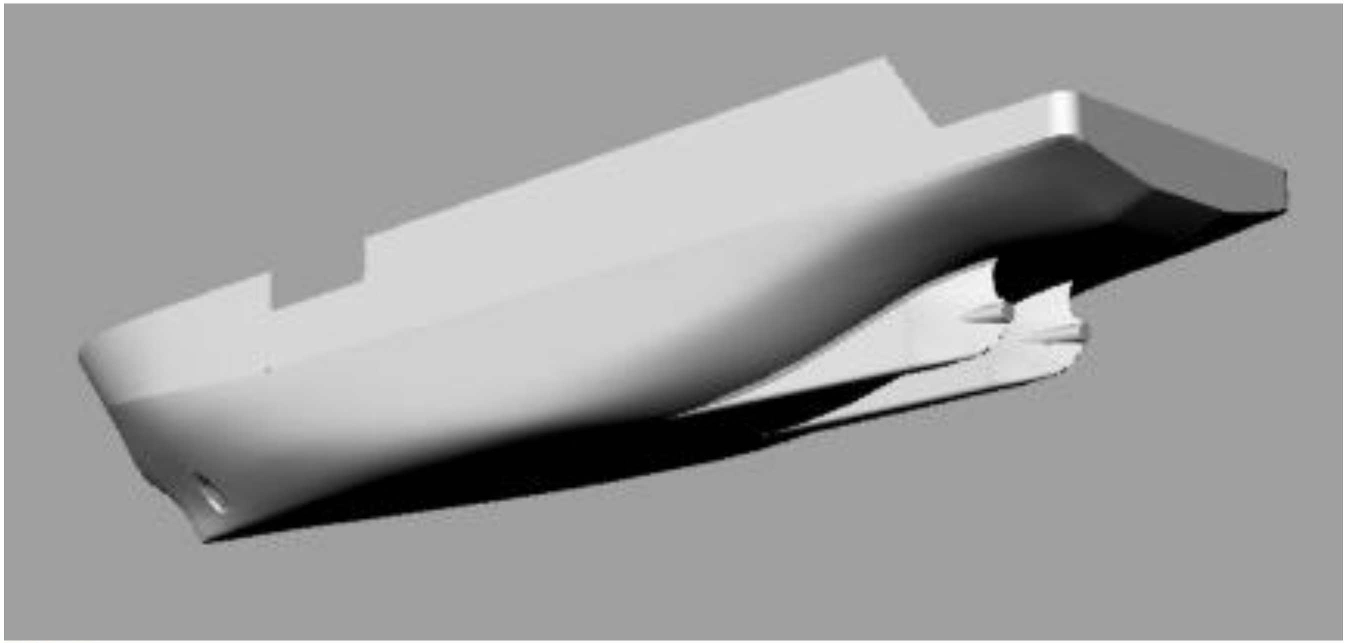
- GUIs can greatly improve usability of software
- Modern software libraries make development easy



3D Modelling and Visualization

- Ship hulls and other 3D surfaces can be modelling highly accurately using parametric surfaces

  $x, y, z = F(u, v)$

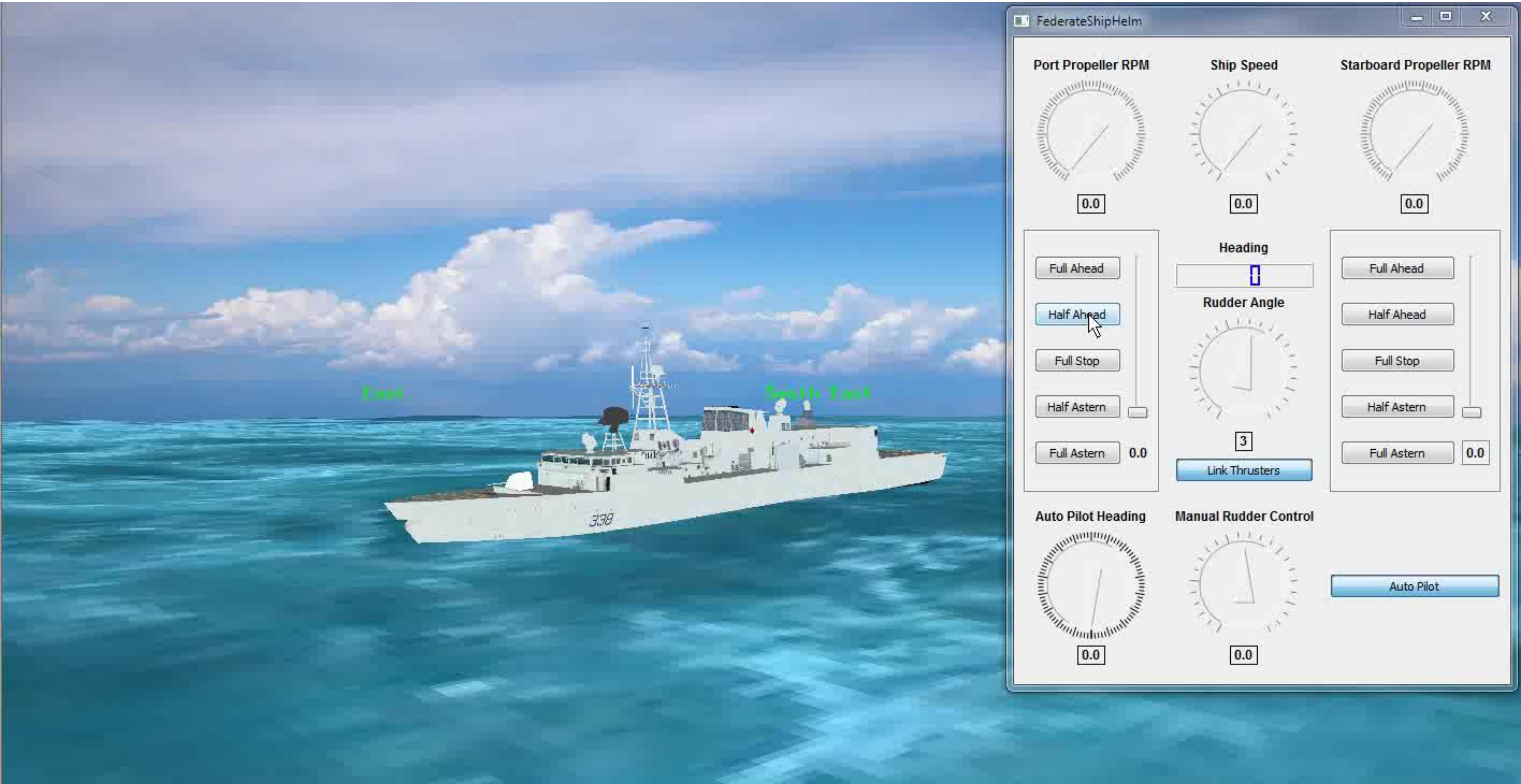


3D Modelling and Visualization

- 3D visualization has become a vital tool for understanding results of complex simulations

Distributed Simulation

- A complex simulation can run on an array of computers linked via a network
- Array of software programs must share data and run in a synchronized manner
- High Level Architecture (Kuhl, Weatherly and Dahmann 1999) is one approach that can be used
  - Specialized skill required
  - Large investment, but potential long-term payoff


East
South East
338
FederateShipHelm
Port Propeller RPM
Ship Speed
Starboard Propeller RPM
0.0
0.0
0.0
Full Ahead
Half Ahead
Full Stop
Half Astern
Full Astern
0.0
Heading
Rudder Angle
3
Link Thrusters
Full Ahead
Half Ahead
Full Stop
Half Astern
Full Astern
0.0
Auto Pilot Heading
Manual Rudder Control
0.0
0.0
Auto Pilot

Parallel Computing

- Computers with multiple processors are now the norm
  - Central processing units (CPUs)
  - Graphic processing units (GPUs)
- Development tools for parallel computing are widely available …
- But, parallel programming can be difficult
- Examples well-suited to parallel processing:
  - Evaluation of Green functions for flow on a hull surface
  - Matrix multiplication

Programming Languages: Factors Influencing Selection

- Numerical computation, including complex numbers
- Ease of programming and maintenance
- Execution speed
- Platform portability
- Availability of libraries, including visualization and user interfaces
- Interoperability with other programming languages
- Availability of programmers and time required to train programmers
- Suitability to problem

Programming Languages: Current Popularity

Language	Rank
Java	2
C++	4
C#	5
Python	8
Fortran	34

Source: TIOBE Index (www.tiobe.com), April 2014

Programming Languages: Current Usage by Authors

- C++
  - Used by authors since early 1990s
  - Object-oriented, high execution speed
  - Requires very skilled programmer
- C#
  - Modern language developed using lessons from C++ and Java
  - Relatively easy to program
  - Runs in virtual machine, giving some performance penalty
- Python
  - Dynamically typed, so variables aren’t declared (*double x* not required)
  - Relatively easy to program and code is concise
  - Slower execution speed because code is interpreted during execution

Matching of Skills To Tasks: Two Types of Contributors

- Domain expert
  - Post-graduate degree in engineering, math, or physics
  - Specialized domain knowledge in hydrodynamics, structural mechanics, or multi-body dynamics
  - Writing papers and/or reports is part of job responsibilities
  - Competent with 1 or 2 higher level languages (e.g., C# and Python)
- Computer scientist
  - Degree(s) in computer science, with proficiency in math and physics
  - Knowledge of relevant naval architecture for writing software
  - Prefers to write software rather than papers or reports
  - Very competent with several computer languages
  - Skills in other areas, such as geometric modelling, visualization, graphical user interfaces, distributed simulation, and computer administration

Matching of Skills To Tasks: Assignment of Work

- Numerical modelling of physical phenomena for hydrodynamics and structural mechanics
  - Domain expert uses higher level language (e.g., C#, MATLAB, Python)
- User interfaces and visualization
  - Computer scientist applies expertise to range of software applications
  - Domain expert can contribute if high-level framework is available
- Interoperability using distributed simulation
  - Computer scientist applies expertise in range of computer languages, including C++
- Code optimization
  - Computer scientist applies expertise in range of computer languages, including re-writing portions of code in faster language

Software Documentation

- Types of documentation
  - Comments within source code
  - Theory reports describing what is being modelled by software
  - User manuals
- Provides many benefits:
  - Improved software maintainability
  - Confidence in software
  - Wider range of software users

Verification and Validation

- Verification:
  - Testing to ensure that software correctly solves equations as intended
  - Can include comparison of results with known solutions:
    - Analytical solutions
    - Other software that is known to be correct
- Validation
  - Testing to ensure that software gives results that compare favourably with “real world”
  - Can include comparison of results with:
    - Model experiments
    - Full-scale trials

Verification Example:
Volume and Added Mass for a Hemisphere at Free Surface

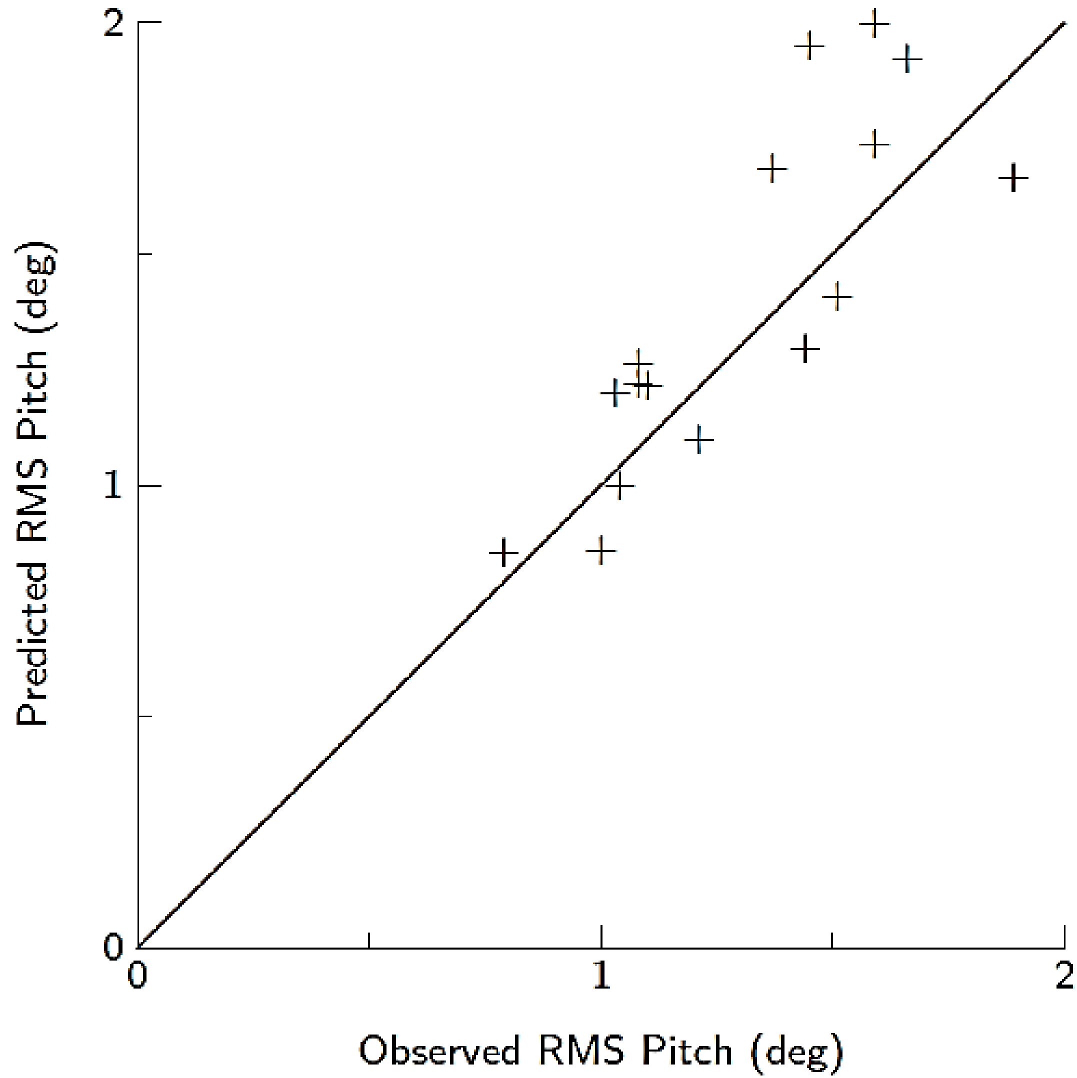
Number of panels	Volume V	Computed/Exact Surge added mass A_{11}	Sway added mass A_{22}
308	0.974	0.978	0.982
704	0.988	0.990	0.990
1972	0.996	0.996	0.996

Agreement and convergence are required

Validation Example:
Motions of a Naval Destroyer from Seakeeping Trials

- Full-scale sea trials are routinely conducted to obtain seakeeping validation data
- Accurate measurements of ship motions and directional wave spectra are essential

Predicted Versus Measured RMS Pitch



Where Are We Going?

- Validation of complex simulations with model tests and full-scale trials
  - Replenishment at sea
  - Launch and recovery of small boats
- More timely and higher quality transfer of CAD data to analysis applications
  - Hydrodynamic models
  - Finite element models
- Routine application of computational fluid dynamics (CFD)
  - Prediction of hull maneuvering forces

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