Principles of Sailing

or

“Main sheets, spinnakers and belaying pins ahoy!”

Paul Pounds

12 March 2013
University of Queensland
But first…

Some house keeping
House keeping

- Tank specifications are now updated on Blackboard and the class website
  
  - ETA of tank: still end of March
# Calendar at a glance

<table>
<thead>
<tr>
<th>Week</th>
<th>Dates</th>
<th>Lecture</th>
<th>Reviews</th>
<th>Demos</th>
<th>Assessment submissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25/2 – 1/3</td>
<td>Introduction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4/3 – 8/3</td>
<td>Principles of Mechatronic Systems design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11/3 – 15/3</td>
<td>Principles of Sailing</td>
<td></td>
<td>Design brief</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>18/3 – 22/3</td>
<td>By request</td>
<td>Progress review 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>25/3 – 29/3</td>
<td>By request</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Break</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>8/4 – 12/4</td>
<td>By request</td>
<td>Progress seminar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>15/4 – 19/4</td>
<td>By request</td>
<td>25% demo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>22/4 – 26/4</td>
<td>By request</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>29/4 – 3/5</td>
<td>By request</td>
<td>Progress review</td>
<td>50% demo</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>6/5 – 10/5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>13/5 – 17/5</td>
<td></td>
<td>75% demo</td>
<td>Preliminary report</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>20/5 – 24/5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>27/5 – 31/5</td>
<td>Closing lecture</td>
<td>Final testing</td>
<td>Final report and addendum</td>
<td></td>
</tr>
</tbody>
</table>
FAQ Roundup

• Our group member hasn’t gotten in touch with us!
  – Have you emailed them? If not, email me and I’ll help you track them down.

• What is the wavelength/part number of the LEDs?
  – Uhhhh…. White visible light. I could theoretically find the part number, but seriously I’m not going to go digging to find it and it won’t really help you. The LED radiation pattern has a 70 deg spread.

• Will the room lights be on/off?
  – There is no room – the testing area is outdoors. However, there will be complete cover overhead, so you (hopefully) won’t have to compete with the Cursed Daystar.

• Can we use a Raspberry Pi?
  – Yes. I won’t respect you in the morning, but yes.
FAQ Roundup

• Can we use an onboard camera?
  – Sure. You can’t use an offboard camera, but onboard is totally ok.

• What do we have to do with the design brief?
  – Show you have understood the design problem. Tell me what part of the project you are undertaking and how it fits with the team’s approach. Highlight the key technical problems. Most of all, convince me that you have actually thought about the problem.

    Better yet – read the Blackboard assessment description!

• Is there a marking rubric available?
  – Yup. Read the Blackboard page.
Design brief design brief

- The objective of the design brief is to convince the client that the student has understood the problem, its scope, and its requirements and has developed insights into how the problem may be addressed. The student must provide a description of the aspects of the project he or she will be working on, a succinct analysis of the key design challenges of these aspects of the problem, the proposed approach to be undertaken in resolving them, and how the student’s proposed solution relates to other subsystems within the project. Students will be assessed on the thoroughness and insight demonstrated in the brief. The design brief is to be no more than two A4 pages.

Assignments are to be submitted through the Faculty of EAIT (Hawken Building 50) assignment chute and require an assignment cover sheet, available from https://student.eait.uq.edu.au/coversheets/
Functional requirements

• Convince me you understand:
  – The problem
  – Its scope
  – Its requirements (and constraints)

• Describe:
  – The aspects you are working on
  – Key challenges of your subtasks (with analysis)
  – Your proposed approach
  – How it relates to the approach of your team
# Marking rubric

## Design Brief – Individual Mark Sheet.

<table>
<thead>
<tr>
<th>Grade Band</th>
<th>Task description (20)</th>
<th>Problem Analysis (30)</th>
<th>Methodology (30)</th>
<th>Design Integration (20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent (85-100%)</td>
<td>Clearly describes the student’s part of the project – its scope and responsibilities. Tasks constitute a valuable, well-motivated and substantive contribution to developing a solution.</td>
<td>Problem broken down systematically. The technical challenges are highlighted and it is obvious how the design problems map to tasks. Well-considered specification provided.</td>
<td>A well justified, comprehensive breakdown of the approach to be taken. Tasks with resources and duration have been logically ordered and associated with logical milestones. Potential risks are reported where appropriate, with associated mitigation strategies.</td>
<td>Captures the most important design decisions and shows how the individual task integrates with the rest of the team. Part of a well-functioning design strategy.</td>
</tr>
<tr>
<td>Very Good (75-85%)</td>
<td>Sets out the work to be done, with some indication of scope or obligations. The student has an assigned task to undertake that will help the group.</td>
<td>Key challenges are recognised and described. Dependencies and prerequisites of major technical problems are discussed. A useful attempt at specification is made.</td>
<td>A somewhat justified list of tasks with resources and duration has been ordered and assigned, with milestones. Risks are considered. Obvious thought has gone into assembling a solution.</td>
<td>Individual components are shown to work as part of a whole, with an indication of the interfaces between functional areas. Obvious communication in developing the solutions.</td>
</tr>
<tr>
<td>Good (65-75%)</td>
<td>Broadly defined task description that maps to a major area of the project, but it less detailed about what is entailed or why that role was assigned.</td>
<td>Statement of the problem captures the essential challenges, and considers some interdependencies. Some analysis considered why these are challenging. Some performance specs.</td>
<td>A weakly justified list of tasks with resources and duration have been ordered and assigned, with illogical milestones. Some sense that thought was given the solution.</td>
<td>Functional breakdown across the project is awkward but each subsystem integrated usefully.</td>
</tr>
<tr>
<td>Satisfactory (50-65%)</td>
<td>Usable task and responsibility assignment provided. Unclear on boundaries or motivations.</td>
<td>Provides statement of what parts are difficult, without delving deeper into why. Little indication of thoughtful analysis. Expected performance requirements are minimal or missing.</td>
<td>A list of tasks with resources and duration has been ordered improperly. Denies apparent analytical consideration.</td>
<td>Collective design is haphazard and interfaces are nonexistent or illogical. Left hand has yet to meet right hand.</td>
</tr>
<tr>
<td>Poor (25-50%)</td>
<td>Some attempt made to provide task assignment and scope.</td>
<td>Simple restatement of the project challenges – limited insight into what makes the problem difficult.</td>
<td>An unjustified list of tasks with resources and duration has been ordered improperly. Denies apparent analytical consideration.</td>
<td>No attempt made at integration</td>
</tr>
<tr>
<td>Very Poor (0-25%)</td>
<td>No attempt made at task scope.</td>
<td>No attempt made at analysis</td>
<td>No attempt made at methodology</td>
<td></td>
</tr>
</tbody>
</table>

**Group mark component:** /100

**Penalties/Bonuses:**

**Final mark:** /100

**Comments:**

**Marker’s Signature:**

**Date:**
Aaarrrr.

On to the sailing!
Sailing – what is it?

• The process of using the wind to propel a floating vessel by way of a foil called a sail
  – Force interaction of two discrete fluid dynamics systems gives rise to controllable propulsion

• Sailing requires no fossil fuels
• Sailing has unlimited range
• Sailing produces no carbon emissions
• Sailing is also very fun!
The parts of a vessel

- Foresail
- Jib
- Mast
- Centreboard or daggerboard
- Rudder
- Mainsheet (via block)
- Tiller
- Boom
- Mainsail
- Deck
- Hull
- Keel
- Waterline
- Draft
- Keel
- Hull
- Mainsheet (via block)
- Centreboard or daggerboard
The parts of a vessel

- Bow
- Stern
- Port
- Starboard
- Fore
- Aft
- Midships

Diagram of a vessel with labeled parts.
Hulls

• Hydrodynamic shapes
  – Provide volume to carry passengers and cargo
  – Push through the water cleanly
  – Provide pitch and roll stability
  – Provide buoyancy
Buoyancy

• Principle of displacement:
  – A body floats in the water at a depth that exactly displaces its mass in water

\[
\begin{array}{c}
\text{Centroid of displaced water} \\
\text{is “centre of buoyancy”*}
\end{array}
\]

*see also ‘metacentric height’
Sails

• A sail is fabric given shape by the wind that generates force from dynamic air pressure

• Sails come in many forms that each work slightly differently to produce propulsion

Jib  Spinnaker  Bermuda  Square  Gaff  Lug  Lanteen
But first…

A quick detour into fluid mechanics
Some thoughts about fluids

• Unsurprisingly, air and water are both fluids
  – Fluids are composed of many tiny particles

• Common false assumptions:
  – Fluids are incompressible
  – Fluids are inviscid
  – Fluids have negligible mass
Boundary conditions

- Consider a shape in an on-coming flow:
  - The flow adheres to the surface of the shape

Blue lines are streamlines; locally tangent to velocity field
Boundary conditions

• Consider a shape in an on-coming flow:
  – The flow adheres to the surface of the shape

Stagnation points

Blue lines are streamlines; locally tangent to velocity field
Boundary conditions

• Pressure increases where flow ‘bunches up’, Decreases where flow ‘spreads out’

Colours represent pressure field
Red = high pressure, green = low pressure
Some intuition

• Consider fluid encountering a corner

Inside turn

Outside turn
Some intuition

• The fluid must follow the surface contour, to satisfy the boundary condition

Air pushed around the corner

Air keeps going?
Some intuition

- The fluid must follow the surface contour, to satisfy the boundary condition

No vacuum here!
An intuitive idea

- The fluid must follow the surface contour, to satisfy the boundary condition

\[\therefore \text{at least some fluid must turn the corner}\]
Some intuition

- Some force must act to decelerate the fluid horizontally and accelerate it vertically
An intuitive idea

- This takes the form of increased pressure inside the corner and decreased pressure outside (suction)
An intuitive idea

• A corresponding force acts on the corner
  – Ie. Newton’s third law
Slightly more complicated

- Now consider a symmetric body in a flow
Slightly more complicated

- It would be reasonable to expect the flow pattern to be symmetric

\[ \text{ie. no resultant force} \]

This is true only in the (aphysical) inviscid flow case
Slightly more complicated

- In reality, viscosity in the flow removes energy along the boundary layer

Unstable stagnation point
Slightly more complicated

• The rear stagnation point shifts to the trailing edge (the Kutta condition)
Slightly more complicated

- This is the basic idea behind wing lift

Decrease in pressure

Increase in pressure
Slightly more complicated

• This is the basic idea behind wing lift

Note: You may also hear reference to “airfoil circulation”, “vortex theory,” “potential flows”, and element or momentum methods. All are valid ways of describing the mechanics of wings
Right…

Back to sailing
How sails work

Two main approaches:

• Parachute
  – Uses drag to drive downwind
  – Force proportional to sail area

• Wind-inflated ram-air parafoil
  – Curvature of air over the airfoil generates lift
  – Sail force acts some distance from the mast; resultant windward torque
How hulls work

• Streamlined hulls create a preferential low-drag direction of travel
  – Can be thought of as an ‘inclined plane’ for changing direction of motion given force
Sailing trim

• When on course and forces/torques balance, the vessel is said to be “in trim”
  – Trim sail force by changing sail angle of attack
  – Trim rudder moment by turning the tiller
### Lateral moment balance

- **Sail force is applied above the hull CoG**
  - High sail forces can tip poorly designed vessels

**Stable**

- Low sail centre of pressure
- Centre of buoyancy above CoG
- Deep keel with fin or centreboard

**Unstable**

- High sail centre of pressure
- CoG above centre of buoyancy
- Shallow keel, no centreboard
Points of sail

**Starboard tacks**
- Close hauled
- Beam reach
- Broad reach or reach downwind

**Port tacks**
- Port close hauled
- Beam reach
- Broad reach or reach downwind
- Running downwind or “with the wind”

**Wind direction**

Head to wind or “in irons”
Beating

- Obviously a vessel cannot sail into the wind
  - Alternating port and starboard close hauled tacks allows cumulative upwind travel

1. Initiate turn with rudder
2. Momentum carries through turn into the wind (sail goes slack)
3. Straighten up on new tack
Gybing

Gybing (or “jibing”) is changing tack from port to starboard (or vice versa) downwind
– This can be a dangerous manoeuver if performed without planning and preparation!

1. Initiate turn with rudder
2. Boom swings across rapidly – everyone ducks!
3. Straighten up on new tack
Useful equations

• The lift, drag and pitching moment of an convex body in laminar flow is given by:

where , and are non-dimensionalised lift, drag and moment coefficients dependent on body geometry*, and is the density of air, is the wing area, and is wind velocity

*Data for airfoils can be found published online or found by experiment or CFD
Questions?

Abaat the beam  Bitter end  Block  Bumboat  Coxswain  Crane  Falkusa  Fantail  Fardage
Abeam  Bunting tosser  Buntingline  Buoy  Cross-trees  Fidd  Fidy
Aground  Bungee  Caboose  Cuddy  Cunningham  Fizo  Fife rail
Alee  Capsize  Capstan  Cunt splice  Cutter  Davit  Davy Jones’ Locker
Aloft  Caravel  Careen  Carrack  Devil seam  Dhow  Dayblink
Amidships  Cat  Catpaws  Cathead  Deadeye  Dhow  Deadeye
Aloft  Catamaran  Catheg  Chafing  Displace  Dinghy  Displace
Athwartships  Chine  Chock  Cleat  Dicer  Dicer  Dicer
Avast  Clew  Clinkerbuilt  Displacement  Disrate  Dog  Dogwatch
Aweigh  Clinkerboard  Coil  Dory  Dreadnought  Edox  Deviation
Athwartships  China  Chock  Clew  Dicer  Dicer  Dicer
Avengers  Cowl  Coaming  Cockpit  Drifter  Drogue  Drogue
Astrawards  Daft  Coach  Drifter  Drogue  Drogue  Drogue
Astrawards  Danke  Coach  Drifter  Drogue  Drogue  Drogue
Astrawards  Dumb  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Edder  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Edie  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Eddy  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Edie  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Eddy  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Edie  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Eddy  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Edie  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Eddy  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Edie  Coach  Drifter  Drogue  Drogue  Drogue
Barracks  Eddy  Coach  Drifter  Drogue  Drogue  Drogue
Tune-in next time for...

Sensor Fusion and Filtering

or

“Making sensors make sense”

Fun fact: The poop deck is not what you think it is.