The Pole to Pole Engineering Challenge

Description:

For this challenge, we were faced with the daunting task of transporting one tonne load from the north to the South Pole. Along with the handicap of using a transportation method that didn't involve flight, harbours or resupplies, we had to ensure that we had all the equipment we needed at the start.

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Transportation

To transport the load, we decided that the best method was to use a ship to carry the load and a vehicle capable of traversing through the harsh conditions of the South Pole. In addition, this ship would also carry enough fuels for the 2.5 months long journey to the South Pole and supplies for our crew.

Using other methods such as transporting the load by road were calculated to be slower than using the boat, as considering we would only be able to use the supplies from the start, we would have to use a vehicle that could transport the load and all the food and equipment for the long journey, which removed any advantage of speed presented by using a road. Plus, that a boat would be necessary later to ferry the load between the land mass and the South Pole.

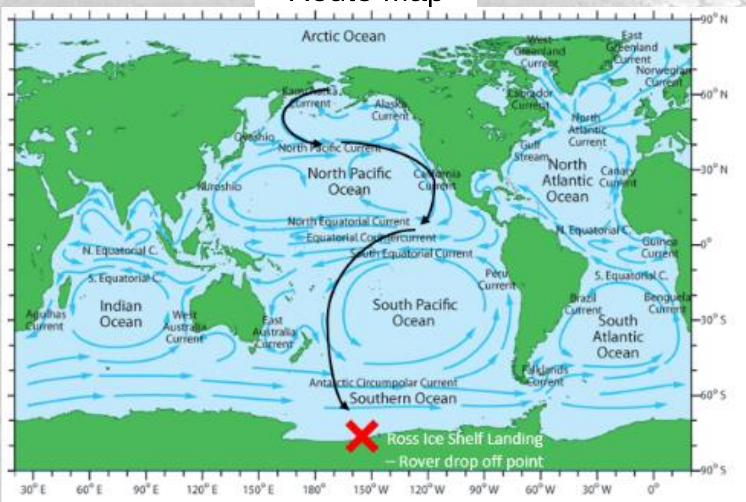
Upon reaching the North Pole, we decided that the best method to transport the load was a rover, with caterpillar tracks for increased stability. While it was considered using an icebreaker ship, however due to costs we decided this method would be far more cost effective. In addition, a bonus of using a rover is its speed is around twice that of the fastest of icebreakers when travelling through ice.

Route

<u>Ship Route:</u>

First, we will start in the Arctic Ocean at the geographic North Pole. From there, the ship will travel south through the north Pacific Ocean by the Alaska than California current to maintain a high speed so to decrease the duration of the journey. From there it will steer to the south equatorial current and by travelling along the east Australia current to reach the Ross Ice Shelf landing, where the rover will be unloaded. This journey is approximately 25,000 kilometres and will take us one and a half months.

Route Map



<u>Rover Route:</u>

Once the rover has been unloaded through a ramp located at the rear of our boat, it will begin the final trek of our journey. From the landing, the rover will travel through the South Pole Transverse, which starts at the Ross Ice Shelf and ends at the geographic South Pole. This is a compacted snow road made of levelled snow and filled crevasses. In addition, there are flags periodically placed along the route, so it will be much easier for our rover drivers to see what way they need to go.

This route is 1,601km, and assuming it would have an average speed of 50 km/h when traversing the route, we estimate it will take the rover 32 hours to travel the 1601 km that is the South Pole transverse. However, we're estimating the total time of travel to be 40 hours, if crew members take shifts of sleeping and driving ensuring that the rover is constantly moving.

Equipment

Sea Transportation

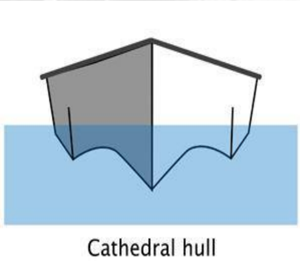
Description:

To initially transport the load from the North Pole, we quickly realised that a boat would be required to transport the load, as the North Pole is in the Arctic Ocean, which is usually covered with between 2-3 metres of solid ice. Not only this, but any vessel we used would also need to have the reserves of fuel needed to travel non-stop to the South Pole, a journey estimated to be 25,000 miles. After researching possible existing ships such as icebreakers to see if we could use them for the journey, we decided that it would likely be necessary to design our own ship to make the journey, which would have to be custom-manufactured.

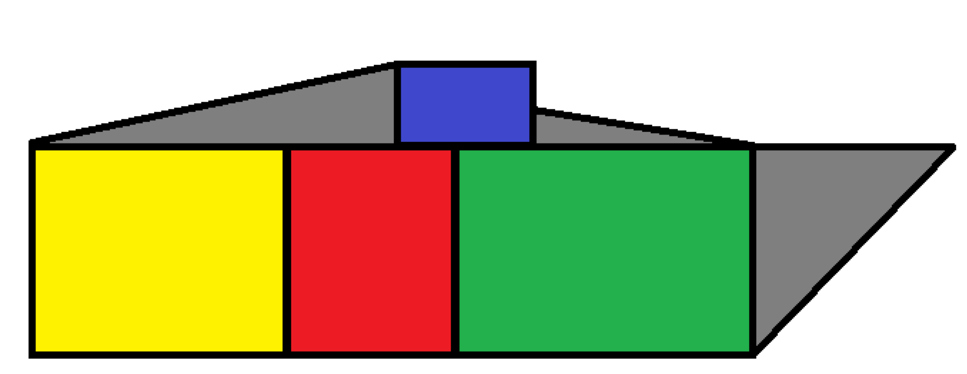
weighing in at around 325 tons and measuring 30 metres long this ship will be capable of taking the rover and the load in a secure and fast manner.

Mechanical Design:

This ship we have designed has been designed with a cathedral hull, selected due to its higher efficiency at speeds and stability which will be essential for the heavy conditions that will face the ship. The hull itself will be made of high strength steel, varying from 42 to 20 mm thick. The 42 mm steel is used in the bow section of the ship, which can cut through icy water, which there is a high risk of especially in the northern Atlantic and near the south pole coast. However, due to the immense weight of steel, we made the decision to create the rest of the ship with 20mm steel which is still strong enough to structurally hold the ship together, while maintaining a relatively low weight. If we had used thinner steel, we would run the risk of ice and the weight of the ship itself damaging or even destroying the vessel, which is a massive concern to the crew welfare. We chose steel over aluminium or a carbon-based hull as it had a great amount of strength for how much it weighs and costs. To make the ship out of aluminium, we would have had to have much thicker walls, which remove the lightweight


Cathedral hull

aspect out of the benefits, and thicker walls meant that there would be an increased cost. Carbon is also not a choice as it is far too expensive for the scale we are going for. The ship itself will be split into several modules, the cargo bay, the utility bay, the living quarters and the control centre.



Key:

Cargo bay (yellow)

measuring 4 by 10 by 6 metres, this area will house the rover, the load and other essential supplies. we have decided to put this at the rear of the ship as it allows for easy unloading of cargo with the use of a ramp. The major advantage of placing this at the rear rather than the front is that it keeps the vessel structurally strong, while remaining both aerodynamic and minimising water resistance.

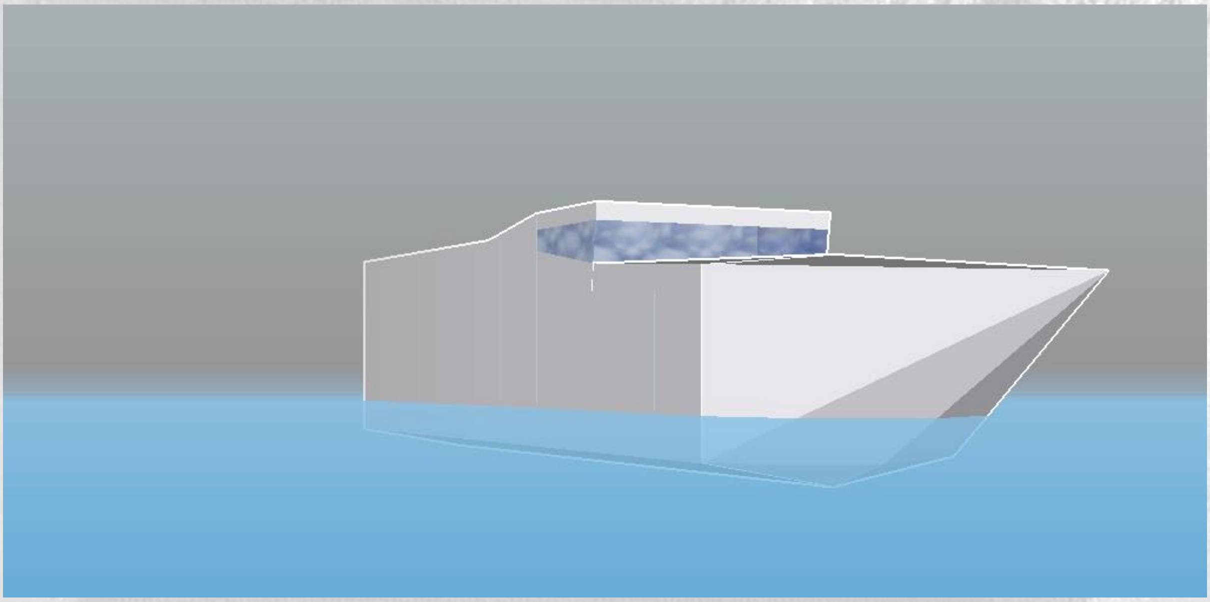
Utility area (red)

within this area will be the engine and all other parts of the propulsion system. This is detailed further below

Crew quarters/living area (green)

Within the crew quarters will be all the needs and requirements for the crew with two cabins, a small galley, storage for food and water, Control centre (blue)

From the control centre, we will have direct access to the ship. It is located physically close to the crew accommodation, so that no transit through the engine bay is required to get to the controls. Inside this area we will be housing Radar, communications and other vital for the running of the ship. This will be using the rolls Royce Aquapilot control system, chosen as it is compatible with our existing set-up, and allows for ease of use and with low power consumption. The user-friendly design will be vital for such a long journey, as it will decrease stress levels within the crew which could jeopardize the mission if issues arise. In addition to this we will use other general displays to monitor communications, navigation and use an EMCP 4 from cat to control the generator, allowing efficiency by reducing the power output when there is a low load level.



Propulsion

We will be using a rolls Royce AZ-PM 1900 azimuth thruster with a cat c18 electrical generator, which will be supplemented with solar panels to both move the ship, and to provide power to the crew. We chose this over a pure diesel design as it removed the need for separate electrical generating as it saved weight on the ship and drove down costs. In addition to this, this setup uses less fuel than a more conventional setup, which allows for a cleaner and more environmentally friendly journey.

This setup cold move our ship at 27 km/h, but due to it being much less fuel hungry and the ship being physically limited to 24.2 km/h while traveling steadily we will run the journey at this speed. As the journey is around 25000km long, it will take 43 days to get from the north pole to the south pole coast. As our generator burns around 120 litres per hour, so the total fuel burn of the trip is 124000 litres which the ship has the capacity for which will be stored low down in the hull to increase stability. This however does not take solar panels into account, which will decrease the fuel burn depending on the time in the sun.

As we will be using an azimuth thruster, we do not need a rudder to steer as the thrust can be rotated to steer the ship. We chose this system as it removes the need for multiple mechanical systems, which could fail at any time. This also allows for much more manoeuvrability at low speeds, which will be vital at the low speeds we would need to unload the rover. However, this unit will be larger than a standard setup, and likely more expensive. Due to the diesel-electric design there will be no need for any transmission or driveshafts, only electrical cables which are easier to fit around the features of the ship.

Control:

Overall:

Automating the boat is important for efficiency. It requires reliable and detailed information to function, which is a potential drawback, but it always removes the need for multiple trained crew members to be operating the ship. This reduces the costs associated with maintaining crew in harsh environments. It also has an interesting trade-off: reducing the probability of human error in favour of increasing the probability of equipment error. We believe that the overall risk is reduced by this method.

A realistic compromise is to have a couple of crewmembers on board along with automated navigation. On a project of this scale, especially considering the chance of critical manufacturing errors, something, be it mechanical or in the software, could go wrong. Having just a couple crewmembers allows them to take shifts while the other rests, so someone is always on-hand to confirm choices made by a computer and to repair small-scale issues. This also means the boat doesn't have to stop in normal operation, reducing the journey time.

GPS:
The main piece of information a navigation algorithm would need is the boat's position. Collecting this in real-time throughout the journey allows the boat to deviate from an initial route, avoid an obstacle, and recalibrate its route. GPS can achieve this, while it's possible downsides of being blocked by tall obstacles or inaccurate at high speeds are irrelevant on a steady boat sailing open waters. Severe weather conditions and temperatures between -10 and 0°C are also not a problem, as the signal frequency of GPS penetrates clouds, rain and snow, and the equipment still functions at low temperatures.

Radar:
The ship needs to be able to avoid other ships of various sizes. On top of this, the ship needs to be able to determine large entities of ice which could slow it down or need to be avoided. For an automated system to avoid obstacles, it needs to be able to detect them and determine their

route. Radar can detect and determine both the position and velocity of objects over 100 miles around the ship, giving the algorithm and the Helmsman more than enough time to steer clear of them.

Radar systems can potentially struggle to handle poor weather conditions, but maritime systems are adapted (e.g. using a different wavelength band) so that the main result is often a slight reduction in range. Interference also should not be a problem on the open sea. Again, the system can function at low temperatures.

Sonar:
A potential pitfall of relying on radar alone is the inability to scan underwater, which could be mitigated by sonar. There should be few submerged obstacles without notable profiles on the surface. The main one is icebergs, with extra consideration to bergy bits and growlers which break off the main iceberg. There are more dedicated ice radars which could supplement our main radar, and sonar could more reliably detect smaller ice bodies, but we feel these are unnecessary costs. Our ship will have a strong hull anyway, and its slow, steady speed means there is little risk of damage due to a collision with smaller bodies. Larger bodies may also appear smaller than they physically are on radio due to their shape or wet, smooth surfaces, but giving them a wide berth should be enough.

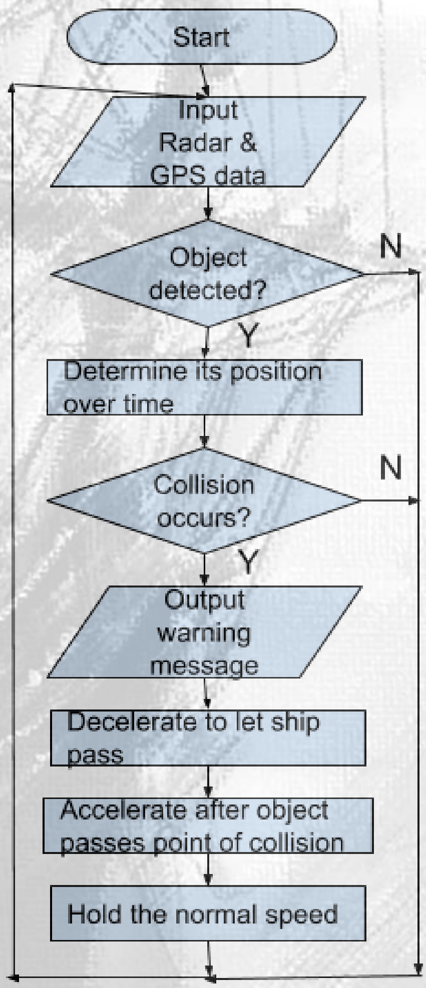
Communications and weather information gathering:
Even with our simplified problem excluding storms, it is important we have weather information. The cheapest way to obtain this (data-wise) is through GRIB files, which provide simple weather forecasts up to 8 days in the future in 12-hour intervals. We will be downloading 24-hour forecasts daily though to ensure that the information is up to date, as the weather can change and travel far in that time.

The GRIB files can be emailed to the crew for free. Accessing the email service and downloading the file takes very little data, so a low monthly data usage plan should cover this. Data usage comes out to around £50 a month, with £4793 for the hardware.

We investigated the various radio devices ships often use and decided that we don't need extra communication due to the sufficiency of what we have and the limitations (such as range) of what we could add.

Automation:

Our data gathering devices will relay their information to a computer which can run a simple algorithm for sailing the ship along an appropriate route as shown below. This can be run during the main part of the journey when the ship sails open seas. The algorithm is more to supplement the helmsman's steering than to be comprehensive. To make a 100% automated ship which can sail with confidence would require redundant information gathering through additional sensors. It can be stopped and restarted at any time along the journey to allow the helmsman to take control.



In order to maintain our constant ideal speed, the computer will also be constantly checking how much power we are getting from our solar panels and making up the rest needed with an appropriate fuel input into the generator.

Land Transportation

Description:

To carry our one tonne load from our boat after arriving at Antarctica to the geographic South Pole, we will need to have a vehicle that can deal with the extremely low temperatures along with the continuous winds to ensure that our load is transported safety with the maximum chance of success.

Tracks:

For this rover, we are going to be using tracks as vehicles using tires, while able to travel well over hard ice or very shallow snow, cannot travel over deeper and softer snow as the vehicle sinks and get stuck. In comparison, the continuous tracks we will use have a larger surface area than if we had steel or rubber tyres for our vehicle, and thus would distribute the weight of the vehicle better, enabling our vehicle to traverse over the soft snow better and with a much lower chance of the vehicle sinking. A further advantage of our rover having continuous tracks is that continuous tracks will give our vehicle better mobility over rough terrain as it will be able to slide over small obstacles such as mounds of ice, rock or snow and can cross small ditches or breaks in the terrain. Furthermore, tracks also give our vehicle a much better manoeuvrability as with continuous tracks our vehicle will be able to turn without having to move forward or backwards by driving the tracks in opposite directions.

For the caterpillar tracks, we decided to have the links connected with steel fingers instead of using rubber metal hinges alternative. This is because of the increase in elasticity of rubber at cold temperatures, which could potentially damage the integrity of the tracks. Finally, since we plan to run using the most optimal amount of crew, the fact that these tracks cannot be punctured or torn presents a huge advantage as this means we won’t have to worry as much about maintenance then we would with wheels.

While there are some disadvantages with using continuous tracks instead of wheels, such as a lower speed and the danger of the entire vehicle being immobilized if we lose a single track, I firmly believe that considering the evidence and the clear advantages of using continuous tracks, that this will be the best choice for our rover.

Fuel:

For the fuel of the rover, we will be using diesel, specifically winter diesel fuel. We are using diesel as it is a highly efficient fuel, which means less weight compared to other fuels. In addition, diesel engines are designed to be able to withstand very high temperatures, which means that they are very durable, so we won't have to worry as much about maintenance. Using winter diesel fuel ensures the diesel doesn't gel in the freezing conditions, as additives added lower the cold filter plugging point of the diesel.

Rover Used:

Considering the elements that our rover requires, we decided to use the GAZ-34039-22 with a rigging complex. Firstly, this vehicle is specifically designed to operate well in difficult climatic conditions over rough terrain. One way it does this is with a pre-autonomous Webasto engine heater, which maintains the engine temperature ensuring that our rover will be able to function at peak efficiency throughout the trek from our landing at the South Pole to the geographic South Pole. Similarly, aside from a standard heater there will also be an independent air heater in the cabin of the rover, helping to keep our drivers comfortable and warm during the expedition.

The maximum speed of this rover on a highway is 60 km/h, so assuming it would have an average speed of 50 km/h, it would take the rover 32 hours to travel the 1601 km that is the South Pole transverse, the route that we will use to transport the load to the geographic South Pole. However, since our crew will stop when they sleep, along with toilet breaks, we're estimating the total time of travel to be 37 hours, if crew members take shifts of sleeping and driving ensuring that the rover is constantly moving.

Because of this, we will pack enough food and drinking water to provide meals for the driver and the secondary driver/engineer for 5 days. These extra provisions will help to sustain the crew in case an incident occurs which causes them to break for some time, such as damage to the vehicle, or if the rover struggles more with the conditions and moves slower than our estimate of 50 km/h. This food will be stored in the storage area between the cabin and the load. This includes heating, which will ensure that the water is kept at room temperature and safe to drink.

To transport the load, we will use the rigging model, as shown in the "Execution options" at Terexs website page for the rover, with a large cargo compartment suitable to transport the load in the safest manner. Luckily, since the load isn't affected by temperature, we don't need to worry about consuming fuel to heat this cargo compartment either. A further advantage of using this rover is that it is designed to operate well amphibiously, which would be useful if the boat cannot get close enough to the shore of the landing, as the rover will be able to drive to the beachhead and begin its journey.

Specifications:

-Engine: D245.12C (diesel engine, capable of using arctic fuel)

-Tracks: Caterpillar tracks with open hinges, with links connected with steel fingers

-Length: 5.72 m

-Width: 2.55 m

-Max speed (highway): 60 km/h

-Weight (with added fuel tanks and 1 tonne load): 5900 kg

Custom Design:

To contend with the specific of our task, the rover have extra fuel tanks attached to the side of the rover to the side of the cargo. This will enable the rover to travel the long distance of the South Pole transverse.

Crew Logistics

Crew:

The crew will consist of a Captain and one Engineer that will be in control of the ship and the rover when the destination has been reached.

Captain:
The captains' responsibilities are the safe transportation of the ship's crew (the Engineer) and the cargo (1 tonne object), the navigation, ships speed, locations (keeping on course) and prevent or avoid hazards. Hazards may include hijackers, pirates, weather and terrain such as rocks, coral or ice. The captain will also be responsible for ensuring we stick to maritime protocols and law of the oceans we travel through along with maintaining safety regulations when travelling.

Engineer:
The Engineer's responsibilities are all operations repair and maintenance of the ship mechanicals and electrics plus the rover (on board the ship or while traveling to the north pole). The ships mechanics will include the engine, generators, boiler (heating), water pumps, cooking equipment. The responsibilities also include starting the engines and regulating engine speed and power in accordance with directions. Record information for engineering logs, such as speed and direction change orders and gauge readings. Engineers perform routine propulsion maintenance; isolate malfunctions observed during operation and perform repairs. The Engineer will also perform general maintenance and repair work for other systems.

Pay:
Median Pay (2015) *
$76,780 for captains, mates and pilots of water vessels
Sources: *U.S. Bureau of Labour Statistics
In pound sterling: £59497.97
Average daily: £163.01

Median Salary (2015) *
$72,870 for all ship engineers
Source: *U.S. Bureau of Labour Statistics
In pound sterling: £56453.48
Average daily: £154.67

Food and water for crew

Food:
The average male calorie intake per day within a healthy, balanced diet, a man needs around 10,500 kJ (2,500 kcal) a day to maintain his weight.
Average weekly calorie intake: 17,500 kcal

Water:
The average male volume of total daily water intake per day is: 3.7 litres (15 cups).
Average weekly water intake: 25.9 litres (105 cups)

Total weight per week

food= 7.6 kilograms water= 51.8 kilograms (0.0509819 imperial tons)

Calculations for food and water:
A standard size tin can hold roughly 400 g; the weight can vary between 385 g and 425 g, depending on the density of the contents.

45 to 65 percent of their daily calories from carbohydrates. Since carbohydrates contain 4 calories in each gram. Calculate carbohydrates requirements by dividing 45 to 65 percent of the calorie needs by four.

10 to 35 percent of their energy intake from protein, according to the Institute of Medicine. Since protein provides 4 calories per gram. Calculate Protein requirements by dividing 10 to 35 percent of the calorie needs by four.

20 to 35 percent of their daily calories from fat. Since fat provides 9 calories per gram. Calculate Fat requirements by dividing 20 to 35 percent of the calorie needs by nine.

calculating percentage intake in kcal transferred into grams:
Carbohydrates
45%= 7875 kcal   1968.75 g
65%= 11375 kcal   2843.75 g
Protein
10%= 1750 kcal   437.5 g
35%= 6125 kcal   1531.25 g
Fat
20%= 3500 kcal   388.88888889 g
35%= 6125 kcal   680.5555556 g
Minimum percentage= 75%
75%= 2795.138889 g

Maximum percentage=135%
135%= 5055.555556

100%= 3726.851852-3744.855967 g
100%= 3800 g

3800g is equal to 9.5 tons per

Cost

Difference expenses:

Price of GAZ-34039 (with custom setup): £50,171.92

Fuel for ship: £119,040

Cost of Crew: £30179.6

References

Vehicle Design:

http://www.rm-terex.com/catalog/gusenichnye-snegobolotokhody/gaz-34039/

Fuel:

https://en.wikipedia.org/wiki/Winter_diesel_fuel

Crew:

https://caloriecontrol.org/converting-calories-to-grams-of-fat/

https://www.weightlossresources.co.uk/calories/calorie_counter/vegetables.htm

https://study.com/articles/Boat_Engineer_Job_Description_Duties_and_Requirements.html

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https://healthyeating.sfgate.com/gram-protein-carbohydrates-contains-many-kilocalories-5978.html