NZ Engineering Science Competition Judges Report 2020

The twelfth annual "NZ Engineering Science Competition" was held from 10am to 6pm on Saturday 1st August 2020. We had 267 teams take part with entries from 81 schools across New Zealand plus our first Cook Island team. The question posed to students this year was:

"How many satellites can be launched into orbit before astronomers on Earth can no longer observe the night sky without interruption?"

This question is very topical as Elon Musk's company SpaceX is planning to launch tens of thousands of Starlink satellites in the near future in an effort to offer easy to access satellite internet. Starlink is not the only planned satellite internet constellation planned, with Amazon Kuiper one potential competitor. Given that only a few thousand satellites are currently in orbit around Earth, it looks like the space around Earth is about to get a whole lot busier in the coming years.

Proposals for satellite internet constellations, which will be placed in a low Earth orbit, have been met with alarm from the astronomical community. Astronomers are concerned that a sudden increase in satellite traffic in low Earth orbit will seriously impact their ability to observe and study the Universe using ground-based telescopes. It is common to think of technological advancement and scientific research going hand in hand, but this issue challenges us to reconsider the nature of the interaction between modern technology and our pursuit of scientific research.

The question this year, which as usual was deliberately open-ended, was mathematically challenging and allowed for many different approaches. A good answer required teams to make a number of sensible assumptions about the problem. Here are a few examples of factors that would affect the final answer that a team could arrive at:

- The geometric configuration of satellites in the night sky, including orbital height.
- The apparent brightness of a satellite and how this impacts an astronomical observation.
- The typical configuration of a telescope, including its field of view and image exposure time.
- How many satellites are required for an observation to be "interrupted".

Judging

Judging was done blind over several rounds by members of the Department of Engineering Science and the Auckland Bioengineering Institute. In round one, each judge selected the best of their allocated entries to advance to round two. In round two, a shortlist of highly commended entries was selected to advance to the final round. A small panel of expert judges reviewed the shortlist and reached a consensus on the winning entry, and the two runners up. Our expert judging panel included members with experience in astrophysics and satellite design. The identity of each team was only revealed to the judges after they had finished selecting the winning entries.

Comments

This was a challenging question from a mathematical modelling perspective, with many possible approaches to arriving at an answer. By extension, many different approaches were seen across the submitted reports. This was an excellent demonstration that complex problems often have no straightforward "correct" answer, and that the modelling process by which the answer is found must be well reasoned and accurately implemented.

A well written report is essential for achieving a spot in the final round of judging. For the teams that made the shortlist, the quality of their writing was excellent, with a clear introduction and background to the problem, a good discussion of their assumptions and limitations, a concise description of their mathematical and/or computational modelling, a well reasoned answer and conclusions, and an effective use of images, diagrams, tables and graphs to showcase their results and support their conclusions.

It is important that each report begins with a summary (or abstract) that outlines the key findings, as well as including the answer to the question. Unfortunately, as in previous years, a number of reports either did not include this opening summary, or did not include the answer obtained within the summary. Some teams presented no answer anywhere within the report, despite otherwise making a good attempt at answering the question, which unfortunately meant an early exit.

Many teams experienced difficulty in identifying the important assumptions for this problem. One of the most commonly missed assumptions was with regards to the apparent brightness of a satellite. As the physical size of a satellite is very small, it’s principal means of interrupting an astronomical image taken at optical wavelengths is through reflecting sunlight back towards the Earth. This is most pronounced during astronomical twilight, which is the short period directly after sunset and before sunrise when only some ground-based observatories are operationally active. Starlink is currently attempting to reduce the reflectivity, or albedo, of their satellites in an effort to reduce its impact on astronomers.

Another problematic assumption was with regards to the characteristics of a typical astronomical observation. The field of view and exposure time could be considered important factors in this problem and, as correctly noted by some teams, these can differ greatly between telescopes. As the competition question gave no indication as to what type of astronomical observation was being considered, an assumption had to be made. An interesting approach, but one not often followed, would have been to consider the problem for a range of different telescope configurations. This would also have been reflective of the real-world situation. Observatories operating only narrow field of view instruments are generally less concerned about the impact of satellite interruption than observatories that operate wide-angle instruments.

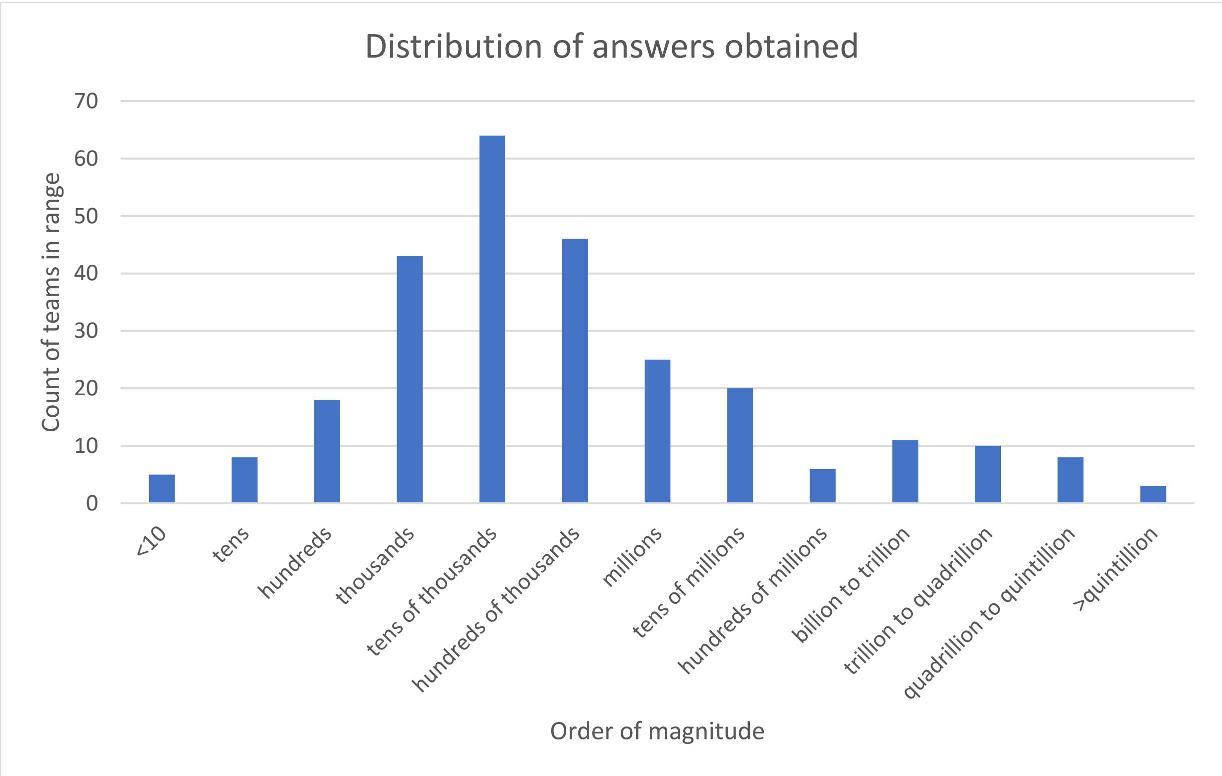
One of the better considered assumptions was with regards to the orbital height of the satellites. As many teams correctly identified, the orbital height of a satellite will affect its orbital velocity, and therefore it’s likelihood of being placed within a given image of the night sky. Starlink and other proposed satellite internet constellations will be predominantly placed in low Earth orbit, which orbit the Earth more frequently. Some teams considered different orbital height scenarios, based on existing ratios of satellites being placed into low, medium and geostationary orbits. This was a commendable approach, though with recent trends it would also be reasonable to assume that most new satellites will be placed into low Earth orbit.

Developing a suitable mathematical model was challenging this year. Predictably, a majority of teams attempted to use a two or three-dimensional geometric modelling approach. A majority of teams used this geometric model to quantify what amount of the night sky would be visible in an astronomical observation and then related this to the number of satellites required for an interruption to occur. A few teams developed a probabilistic model of the problem, which was an interesting approach. The top entries described their model clearly and concisely, often with the aid of a diagram and a well written description of the governing equations. Unfortunately, many teams explained their model either poorly or not at all, writing down equations with no context given as to where the equation came from or what the variables in them represented.

Although not necessary to be considered a top entry, an impressive number of teams used computational programming to support their mathematical modelling. It was interesting to see the choice of programming language somewhat reflect that of the wider scientific community. Python was the most popular, and other languages used included C++, Java and MATLAB. Although it is encouraging to see attempts to incorporate computer programming into finding an answer, it is important to note that it must add value to the analysis. If performing the calculation with a calculator would have been quicker and just as effective, then the time invested into writing the computer code may have been better spent elsewhere. A small number of teams were able to implement a computer modelling approach that provided simulated data to support their conclusions and final answer. This is quite an accomplishment given the short amount of time available.

An important part of the modelling process is to compare results with existing literature. One of the challenges of the question this year is that it is a fairly recent development, and only limited research on the impact of increased satellite numbers on obervations has been done by the astronomical community. See "Impact of satellite constellations on astronomical observations with ESO telescopes in the visible and infrared domains, *Astronomy & Astrophysics 2020*" for one example of a recent study. It would have been good to see more teams reference existing research and attempt to compare and critically assess their final answer. It is also important that any existing research used or considered is referenced appropriately in the team report.

The answers that teams obtained varied widely, spanning a huge range of orders of magnitude. The lowest answer was 0 (i.e. already we can't observe the night sky without interruption) while the highest answer was 3.2 octillion (an octillion is a 1 followed by 27 zeros). A summary of the distribution of answers obtained is shown below (note that this does not exactly match the total number of teams as some teams found no answer while other teams found multiple answers).



Results

The Pullan Prize for first place ($6000)

Team 1200 from Auckland Grammar School, Auckland (Year 13): Nathan Jiaming Chen, Zhiyuan Qi, James Patrick Harnett, Luke William McCallum

Runners Up ($2000 for each team)

Team 1048 from Kristin School, Auckland (Year 12): Kevin Wei, Ethan Miller-Goulter, Sally Minkyo Kim, Hee Seo Kim

Team 1274 from Macleans College, Auckland (Year 13): Darsh Chaudhari, Daniel Ahn, Jimmy Zhou, Yunge Yu

Highly Commended

- Team 1035 from Liston College, Auckland (Year 13): Matthew Ross, Micah Sullivan, Jacob Mathew, Michael Kennedy
- Team 1052 from Kristin School, Auckland (Year 13): Elim Lin, John Yu, Kunli Zhang, Vanessa Xiong
- Team 1100 from King's College, Auckland (Year 12/13): Hanbo Xie, Nathaniel Masfen-Yan, Oliver Vannoort, Ethan Kyle
- Team 1132 from Rangitoto College, Auckland (Year 13): Julia Zhang, Sisya Jiang, Anna Hua, Andrew Lee
- Team 1158 from Auckland Grammar School, Auckland (Year 13): Ayaan Shahidali Saiyad, Mackinley He, Sven Jansen-Snip, Arnav Shekaran
- Team 1160 from Macleans College, Auckland (Year 12/13): Abhinav Chawla, Ranudi Lelwala, Michael He, Sanjit Ramesh Chandran
- Team 1237 from King's High School, Dunedin (Year 11/12): Narayan Shastri, Samuel Blackwood, Radin Vajedi, Scott Butler-Pollock
- Team 1254 from John McGlashan College, Dunedin (Year 13): Joe Mu, Ben Monaghan, Simon Basel, Chris Denton

Participation

We had 267 teams from 82 schools participate this year.

We had many "Action shot" photos submitted during the course of the day. These photos were uploaded to our department facebook page and can be viewed at: www.facebook.com/engsci

Macleans College had the most entries from a single school, with 18 teams competing. They were followed by Rangitoto College and Epsom Girls Grammar School with16 and 14 teams, respectively, competing. See overleaf for a complete list of schools and how many teams they entered.

ACG Parnell College	12	Nelson College for Girls	1
ACG Strathallan College	4	New Plymouth Girls’ High School	1
ACG Sunderland	1	One Tree Hill College	4
Albany Senior High School	2	Nelson College	1
Aquinas College	3	Otago Boys’ High School	1
Auckland Girls’ Grammar School	1	Otago Girls’ High School	1
Auckland Grammar School	5	Pakuranga College	5
Auckland International College	2	Palmerston North Boys' High School	1
Avondale College	11	Palmerston North Girls' High School	2
Baradene College	1	Papatoetoe High School	3
Birkenhead College	1	Pukekohe High School	5
Botany Downs Secondary College	6	Rangitoto College	16
Buller High School	1	Rathkeale College	3
Burnside High School	5	Rosehill College	1
Cambridge High School	1	Rosmini College	1
Christchurch Girls' High School	1	Rutherford College	1
Dunstan High School	5	Sacred Heart College	1
Epsom Girls Grammar School	14	Saint Kentigern College	2
Fraser High School	2	Samuel Marsden Collegiate School	4
Freyberg High School	2	Scots College	2
Glendowie College	1	Selwyn College	1
Green Bay High School	3	St Bedes College	1
Hamilton Girls’ High School	2	St Cuthbert's College	6
Hauraki Plains College	2	St Kevin’s College	2
Havelock North High School	2	St Mary’s College (Wellington)	1
Hobsonville Point Secondary School	1	St Matthew's Collegiate	3
Hutt International Boys’ School	2	St Paul's Collegiate (Hamilton)	1
Hutt Valley High School	1	St Peter's School (Cambridge)	3
John McGlashan College	2	Takapuna Grammar School	4
Kaitaia College	1	Tauranga Boys’ College	4
Kāpiti College	2	Tauranga Girls’ College	5
King's College	7	Tereora College	1
Kings High School	2	Timaru Boys High	1
Kristin School	6	Waimea College	2
Liston College	1	Wairarapa College	1
Logan Park High School	1	Wellington Girls’ College	1
Long Bay College	4	Western Springs College	2
Lynfield College	5	Westlake Boys High School	7
Macleans College	18	Westlake Girls High School	7
Massey High School	3	Whanganui High School	2
Matamata College	1	Whangaparaoa College	5
Mount Albert Grammar School	5	Whangarei Boys High School	1