Interstellar Travel

Per Ardua Ad Astra

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Ian D. K. Kelly

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The Author

Ian D. K. Kelly is a computer scientist, who trained as a mathematician. He is interested in almost everything – including linguistics, fairy stories, philosophy, and astronomy. Ian plays the piano (and church organ), teaches music and conducts several choirs, has written books about computer translation (that's computers translating between *human* languages), pantomimes *("Oh no he hasn't!" "Oh yes he has!"*), and novels for both children and adults. He claims that if he gets to Heaven, he'll be a librarian, will hear the real end of J. S. Bach's *The Art of Fugue* – and drink fine wine all day.

<PORTRAIT>

Ian D. K. Kelly

Publications

Emerald Pie, 2007, Agrintha Books, Exeter, ISBN 978-0-9553399-1-2 A children's novel. Suitable for children from seven years old.

A Lad in Knaphill, and His Magic Lamp, 2007, Agrintha Books, Exeter, ISBN 978-0-9553399-5-0 and *Cinderella and Her Bearded Sisters*, 2007, Agrintha Books, Exeter, ISBN 978-0-9553399-6-7. These are pantomimes ("*Oh no they're not!*" "*Oh yes they are!*" "*Not that joke again!*"). You are warmly invited to use these pantomimes, and make any alterations to them for your own purposes – but if you do use them, *please* send a donation to **Knaphill Methodist Church, Surrey GU21 2DR, UK.** Thank you.

"PROTRAN – An Introductory Description of a General Translator", in **Ebert, R., Lügger, J., Goeke, R.** *Practice in Software Adaption and Maintenance*, 1980, North Holland, ISBN 0-444-85449-5

"PROTRAN – A generalised translation tool for natural and algorithmic languages", in *Overcoming the Language Barrier*, Verlag Dokumentation, Munich 1977. Proceedings of the third European Congress on Information Systems and Networks, EEC. ISBN 3-7940-5184-X

"Thesaurus Vectors", 1980, Newsletter No. 9, Natural Language Translation Specialist Group (BCS).

With **Tucker, J.V.H.**: "Jesus Smithson" in **Boas, Guy**: *A Teacher's Story*, 1963, Macmillan, London

Progress In Machine Translation: Natural Language and Personal Computers, 1989, Sigma Press & John Wiley, ISBN 1-85058-156-8

With **Goshawke, W., Wigg, J.D.**: *Computer Translation of Natural Language*, 1987, Sigma Press & Halstead Press (John Wiley), ISBN 1-85058-056-1 and 0-470-20913-5

The Carpenter's Carpet, 2007, Agrintha Books, Exeter, ISBN 978-0-9553399-3-6 Teaching stories from the world's religions and traditions. Suitable for children from five years old.

How to Read This Book.

Read it through, for the first time ignoring all the footnotes, and all the sections that are shaded – these are merely technical descriptions and justifications. They are *important* technical descriptions, and the argument *does* depend upon them, but – in the fist instance – you should trust me. At the end you will know the main thrust of what I am saying.

Then read it through again, this time reading and checking the figures and the footnotes and the shaded sections and the technical niceties, as you see fit. If you find any errors, or you can show that my conclusions are incorrect or do not follow from the figures do please let me know either by letter to the publisher or by e-mail to idkk@idkk.com or both. Or you could yourself write a book presenting better arguments or counter arguments - I would be delighted to hear of either.

Above all, *enjoy* reading this: it is about a very important topic – more important that most people currently realise.

Acknowledgements

Where to begin? Where to end? I have had many suggestions and much help. I have received a lot of advice, and taken very little of it. The facts and good ideas are all due to other people – just the mistakes are mine.

At the very least I have to thank for (variously) their ideas, their support, their teaching, their examples, their criticisms (some slight, some deep), their friendship and their love [names in alphabetic order by surname]: Shaheen Aziz Ahmed [who, many years ago, tried to teach me scholarship, art-appreciation, and Urdu]; "Russell": J. W. R. Anderson [*Rux0r*]; Professor Archbold (UCL) [the first person ever to call me "Mr. Kelly", and a masterly teacher of algebra]; Marcella Arnow [charming friend and intellectually focused work-mate: the most English American you can imagine]; Peter Bacon [charming Christian wit with, I believe, a frog named after him]; Grace Barr; James Barr [perfect gentleman, and devout Christian]; Mr. L. Berkeley [inspired teacher of history, lovingly known to generations of pupils as *Buffalo Bill*]; Allan Bouchard; Judith Bouchard; Pamela Bourne;

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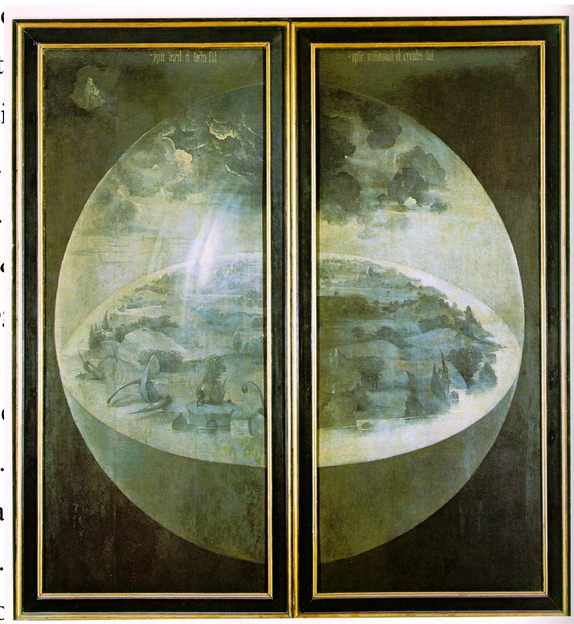
Edmund Stephen-Smith [*ESS*]; Tom Stockwell [brilliant teacher of physics and scientific method: alas, I have forgotten much of both]; Poh-Teen Tang; Tim Upton; Vince West; David Wigg; Tom Wilson [wonderful teacher of mathematics, musician, and gentleman]; Andy G. M. Wood [*AGMW*] (not “Woods” – there’s only one of him). And [non-alphabetically] my dear family: my patient, beautiful, charming, irreplaceable wife Gay [How do put up with me, Gizzie? I am thrilled that you do.]; our fantastic children Benjamin and Miranda; and my wonderful, wonderful parents, Percy and Vera, whom I can never thank enough.

If there are names omitted from this list of friends and absent friends, it is from my stupid forgetfulness, not spite. Thank you all for your ideas, help, patience, friendship and love over the years.

Summary Contents



The Garden of Earthly Delights (doors): Hieronymus Bosch

Detailed Contents

<IMAGE (drawing) OF PLANET ORBITS>

The Asteroid Belt

Synopsis

The overall argument is that Interstellar Travel ("IT") is possible, and necessary, and costly – and interesting. I show it is possible by describing the first part of how it could be achieved; with a discussion of mankind's future annihilation I show it to be necessary; and by referring back to the possible techniques of its achievement, give it an initial costing. I am passionately interested in the topic, and I hope you too will be when you have read this book.

You don't need a lot of prior knowledge to start reading. True, this book goes through areas of sociology and economics and physics and astrophysics and biology and astronomy and mathematics. There are sections about chemistry and computers and nuclear energy and cooking and education and politics (both local and international). But I assume, throughout, that you are the ordinary, non-technical reader – *everyone* can read this.

What is meant by "Interstellar Travel"? It means transporting an appreciable number of living human beings beyond from the confines of the Solar System as we know it. This is *not* talking about just exploring parts of the Solar System – just going to the other local planets – but a journey that is very much longer than that. The size of the Solar System is measured in (at most) a few "light days" (the distance light would travel in a couple of days): the nearest star is more than four light *years* away[1]. The journeys considered here are several hundreds – or thousands – of light-years in length. If the Interstellar Ships are designed correctly, the journeys might even be millions of light years in length.

Looking at how viable Interstellar Travel (IT) might be achieved, we see that the IT project would not be small, and would not be easy. One possible technique of creating a ship would be to choose

1 A light-year is a *distance*, not a time. It is the distance light would travel in a year. One light-second is (about) 300,000 kilo-meters, or 3E8 meters. A light-minute is about 3E8·60=1.8E10 meters. A light day is about 1.8E10·1440=2.6E13 meters. A light year is about 3.14E7·3E8=9.46E15 meters (nearly 1E16 meters). Here we are considering journeys of up to 1E4·1E16=1E20 meters.

an existing rock in the Solar system and make it habitable, and then consider how it can be moved over very long distances with human traveller. So the possibility is considered of taking a large asteroid, hollowing out its core as the living space and projecting that asteroid by ejecting (in small bursts) its hollowed-out core. Other possibilities are also considered. There are discussions on how much energy and what timescales would be required. There are also enquiries on how long the resulting environment (habitat) might remain stable, and how long an isolated community could live in such an environment – scientific and sociological stability.

Why is this IT project necessary? Because mankind is doomed. There are various – numerous – disasters waiting to happen. Some of these disasters will extinguish mankind. Note – "*will* extinguish" not "*might* extinguish". We – humankind – are in serious danger, here on Earth, and unless there is a subset of mankind that gets away from this planet then the annihilation clock is ticking for us – and ticking loudly[2]. It is we ourselves that have helped wind this clock.

If we are going to hollow out an asteroid, we have to get to the asteroid, and we have to take equipment to the asteroid, and we have to have advanced manufacturing at the asteroid. We have to take people to that work area, and we have to take all the basic ingredients for a "bio dome". Being a large project, it is costly. We discuss just how costly, and the economic impact (and advantages) of this project. If we choose any of the other techniques we have to have the same discussions.

Finally we ask "When can it be started?" So: Can we? Must we? How? What scale? When?

2 The various future disasters include the Sun going nova – the destruction of the Solar System by that enormous stellar explosion – meteoric impacts on the Earth, nuclear disaster, biological attack, technological mishap ("the grey goo"), and fatal pollution. Each of these has its own probability of occurring. The first listed here – the Sun going nova – is the furthest away in time – and the most completely certain.

Destination

Where are we Going?

This is about interstellar travel: it is not science fiction document, but science and sociological fact – if you wish to make fiction from it, be my guest! My training as an engineer has been incomplete, and others can fill the (many) holes in this discussion – but the idea's core is here.

Per Ardua ad Astra is the motto of the Royal Air Force – "by effort to the stars". I do not believe that the bulk of what I describe here will be achieved in my lifetime. I urge you, though, to think about it. Every generation needs its cathedrals, its great works, its potentially impossible dreams. Travel to the stars is, for us now, the ultimate physical frontier. And I will argue it is an essential part of our future.

Answering the question as to *which* stars we should first visit is complex.

The Questions

There are five main questions to consider, with many subordinate questions hanging off them. The five main questions are:

Can it be done – is it possible for us to go to the stars?
Can we?

Do we have to go to the stars? Is there compulsion?
Must we?

How can we get to the stars – what is the engineering involved?
How?

What is the scale of the operation, and its cost? How much?
What scale?

How long will it take, and how often can we repeat it?
When?

Which stars do we visit?
Where?

The main sections of this document consider these six main points, with a number of the subordinate questions.

The conclusions cannot be summed up in one sentence – but the summary of the summary is:

- i) yes, we *can* travel to the stars, and
- ii) yes, we *must* travel there, or we – all of mankind – are utterly doomed, and
- iii) there is engineering that will get us there – even though there are some developments that have to be made, and
- iv) the scale is considerable, the cost is great (and discussed in much more detail here) – but the negative costs are even greater, and
- v) we could (and must) start the first journey[3] within 100 years – or within a shorter period, if we can get the political <u>and</u> <u>social</u> will.

Can we? Yes. *Must we?* Yes – or we are doomed as a species.

---

3 Or at least, the major engineering towards a journey.

How? By making an existing celestial body habitable (for example, by hollowing out an asteroid and impelling it forward[4]). *What scale?* At a cost of $\$3 \cdot 10^{14}$ spread over 100 years[5]. *When?* We could – and we should – start right now, and repeat it many times, but need political and social will to do so. Where? There are a large number of possibilities.

4 The technique of propulsion is a major part of the discussion. We may, perhaps, choose to let hydrogen (fusion) bombs off behind the ship *a la* project Daedalus, or we may discover a more efficient technique as we search.

5 This is the most uncertain figure. It is probably between $\$2 \cdot 10^{14}$ and $\$1 \cdot 10^{16}$, at the 2010 value for the dollar – but it might be even more. The section on Costs (Error: Reference source not found) is a fuller discussion (concluding Error: Reference source not found).

Why?

The sixth question – the one not fully posed here – "*Why?*" is difficult, as there are many levels of reason. There is no way adventure can be explained to a non-adventurer. "Because it is there" is one reason enough, or perhaps "because we have to". You may personally believe that this is something we – mankind – *must* do and *will* do, or the contrary. I cannot persuade you it is a good idea if you are convinced otherwise – or too scared to accept its necessity.

If we do not think of our future amongst the stars, we – humankind – are doomed to soon die on this planet, with absolute certainty. If we *do* go beyond our tiny Solar System, then there is a chance – just a chance – that we, through our descendants, will survive beyond the 8 million years that (currently) seems to be the real outer limit of our expected species lifetime[6] (Ref: [Gott2001] p.210).

Scientists are encouraged to consider questions that start "What?" or "When?" or "How?" or "Who?", and the question "Why?" is sometimes called "The Devil's Question", and it is not always easy to determine which sort of "Why?" is meant, when it is asked.

Overcrowding

In the short term (at most a few hundred years) if we do nothing we are doomed to run out of space and food. Growing at only 1% per year would mean that in 100 years the world's population would be well over 16 thousand million (16,000,000,000) – assuming we are starting with "only" about six and a half thousand million now. In 200 years it would be 43 thousand million (43,000,000,000) and in 500 years it would be (gulp!) 868 thousand million (868,000,000,000). With over $6.5 \cdot 10^9$ (6,500,000,000) we are already overcrowded – at $8.6 \cdot 10^{11}$ people we would (metaphorically) be standing on each other's shoulders.

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6 We can expect, as a species, to exist for perhaps another 8,000,000 years (ref: [Gott2001], p.210), and at most (with 95% probability) another 12 million years. Even if we multiply this surprising figure by 10 to give 120 million years [$1.2 \cdot 10^8$], we are still falling short of the actually experienced lifetime of the (group) dinosaurs (in excess of 160 million years)! (Ref: [Brit1988], V.4, p104).

So we have to stop before then. Overcrowding will kill us[7].

Pollution

And there is pollution. The number of people with (for example) asthma is growing – not just because the population is growing, but in proportion to the population. We have (inevitably world wide) an increase in the carbon dioxide and methane and dust being pumped into the atmosphere by man's actions. My family in Ireland tell me that they will not eat fish caught in the seas between Ireland and Britain as they fear that those fish will be contaminated with radioactivity. And you personally have met and heard of many other examples more serious than that

In the Western world – the arrogantly named "first world" – there is[8] an increase in life expectancy. But this is not always the case in the truly-named third world. We have, in countries like Zaire and Zimbabwe, terrible mortality arising from AIDS and political theft of food. We have, all over the African continent, the rape of nature, and the destruction of natural resources. We have, in Russia, hideous mis-management of water resources – to the extent that a complete sea has been dried up because of man's intervention. We have in China, and the far East, seemingly unrestrained pollution poured into the atmosphere out of "economic necessity". You can see in South America many instances of river pollution, forest destruction, the surface degradation of the land – again from "economic wishes"

And, no, they are *not* economic necessities – they are just wishes. This is not a polemical tract, telling you how mankind should reorganise so that all can be fed, all can be clothed, all can be healthy – but it is a matter of fact – of known fact – that there is already sufficient food on the planet to feed us all, but that food is unfairly distributed.

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7 The figures quoted are based on just 1% population growth. We have – observably – more than that.

8 For the moment – it will not always be the case. There is a suggestion that even in the USA and Britain the children of the next generation may have shorter life-spans than the children of this generation.

Nova

In the longer term, Sol[9] (the Sun) will go nova. We are pretty certain of this[10]. So even if we do not die from overcrowding (starvation, atomic war, biological annihilation, etc.), we will – in less than $5.5 \cdot 10^9$ years – die from an exploding sun. Just 1 AU from an exploding star is not a healthy place to be[11]. If at that time mankind is confined to that point in space, then mankind is doomed. Doomed with complete, unquestionable finality.

We have to do something. We have to do something big. If we do not, we will all perish – the whole of humanity. The stakes could not be higher.

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9 The Sun is named Sol, as a proper star name. The Earth – the planet you are now on – is named Terra, and the Moon is called Luna. In this document I intend to use these proper names.

10 In the spectral sequence of stars – which has the delightful mnemonic of "**O** **B**e **A** **F**ine **G**irl, **K**iss **M**e **R**ight **N**ow **S**weetheart" – Sol is smack in the middle – a G type star. These stars go nova when they reach a particular size. Sol will reach that size in between 5.0E+9 and 5.5E+9 years from now.

11 An AU is an Astronomical Unit, which is (by definition) the mean distance form the Earth to the Sun – so of course we are one AU away! That is about ninety-three million miles or just under 150 million kilometres.

Urgency

When should we commence the work towards interstellar travel?

In once sense, we have already started it. Although at the time I first wrote this paragraph (October 2003) there had been an interval of over 20 years, mankind *has* been to the Moon, Luna, and we are planning (though with political prevarication and budgetary weakness) manned trips to Mars[12].

If the expected lifetime of the planet is five thousand million years we cannot wait four thousand million years before we start work – that would be far too late. If our expected species lifetime is 8 million years, we cannot afford to wait 7.5 million years before we start work – that also would be far too late. If we die of hideous overcrowding in 500 years, we cannot afford to wait 400 years before we start to work on the problem – that again would be too late.

Nor can we afford to wait for the technology to be right – it will not just come right by itself – we have to choose to do the work, choose to do the research, choose to do the development. By working on it, the technology will be forced to come right[13]. Much of the engineering required to reach Luna, for example, arose simply because there was a (political and social) will to get there: the technology followed the desire.

So we have to start work now – right now. For now – in the early years of the twenty-first century– we have the nucleus of the necessary technology, we have the necessary wealth, and we have breathing-space enough to work on hard problems before they become so pressingly urgent that we either panic into bad solutions or give up and submit to tragedy. But it's a narrow time window.

Will we do it? That I cannot say. If it were just the choice of the engineers, just the choice of the geeks (*us* geeks!), then – yes – we would build interstellar craft. It is, however, a political choice, and

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12 "*I always knew I would see the first man on the moon: I never dreamed I would see the last.*" [Jerry Pournelle]

13 I do not object in any way to the first language spoken on Mars being, for example, Mandarin Chinese: I *do*, however, object to *no* language being spoken on Mars, ever.

politicians (for all their fine words) have only short-term views. And this is, above all, a long-term project. This is a decision, a project, that is too important for the petty politicians – what genius of social engineering will get it started, though, I cannot yet fathom.

The Destination

One major decision – at least from a psychological point of view is "are we going somewhere, or are we just going?" That is *"Where?"*: do we have a final destination – a specific place each ship is aiming for, or are we simply launching the ships to be worlds in themselves, distant from Terra?

Although this is a major question, it is once whose answer we can change even after we have set out. A ship could, for example, set out with a specific destination in mind, but partway there decide to just continue travelling. A ship could suffer a disaster (an engineering mishap) en route, and find that it no longer has the ability to reduce speed adequately to land (stop) anywhere – it is then compelled to continue travelling at very high speeds, until (perhaps – and *very* improbably) it catches up with something that was initially moving away from it very fast.

To start with, in our engineering, we will assume that we are going somewhere – each ship has a destination, and that we have to try to retain the ability to slow down again. It is just as glorious and worthwhile a trip should we have no final destination, though, other than the journey itself. The travellers too must remember that. We are possibly designing ships with no final, fixed destination but themselves – and the future.

Approximations

In this book the figures are approximate. The whole subject is still very conjectural, and it is too early to make precise calculations. Accurate calculations, however, *can* be made – and, if we are to achieve our ends – *must* and *will* be made. When you are evaluating these figures, do not object if they are few percent out – but (by all means) object of they are tens of percent or orders of magnitude out.

Where there are conjectures or uncertainties I also indicate my (personal) degree of certainty as to the validity of the figures quoted. My certainty is expressed in one of two ways: (i) as a valid range for the figure (*e.g.* there is a better than 95% probability that I will live "more than one day from the time of my writing this sentence, but less than a hundred years from that time")[14] or (ii) my belief in the accuracy of the figure quoted (*e.g.* I am more than 99% certain that I am 58 years old, at the time of writing). Where these certainties are expressed they may be written in the forms "[range](probability)" or "value{certainty}": *e.g.* "[1 day, 100 years](>95%)" or "58 years{>99%}".

I assume in writing my formulæ that you have a grasp of only simple mathematics – what is now called "GCSE Level" in the UK (and used to be called "O Level"). I do *not* assume that you can understand integral calculus or non-Euclidean geometry or tensor calculus or how to calculate the volume of water required to support a million frogs. If you *can* understand all of these, so much the better – but I doubt that the calculus or the geometry will be of any use. The frogs might. (See Ref. [Offw2005]).

Because the meaning of "million" is held in common on both sides of the Atlantic, and means 10^6 (or 1.0E+6) on both sides, that is a word that can be safely used. We will be talking about much larger numbers, however, and – alas – words like "billion" and "trillion" cannot be agreed upon. To an old Englishman like myself, "billion" is "bi-million" or 10^{12} (1.0E+12) – but in the USA it is a mere 10^9

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14 There is a Yiddish blessing of "*May you live to be one hundred and twenty*". Whether that is a blessing or really a curse I am not completely certain! (See also Gen. 6:3).

(1.0E+9)[15]. Similarly for "trillion" which is either a "tri-million" of 10^{18} (1.0E+18) or – in the USA – 10^{12} (1.0E+12). Hence these larger words cannot safely be used without ambiguity.).

In these notations, the overall cost of this project could be written as [$2E+14,$1E+16].

I am also avowing my beliefs. Because I desire something and because I believe something it does not follow that I am right. You have to judge. The arguments given here are (invariably) one-sided. It is for you to find valid counter-arguments – to correct my figures, tutor me in physics, criticise my engineering, and so on. Do not be fooled by my erudite quotations – *quidquid in latine dictum sit, alta videtur*[16] – think for yourself. Tell me what you think by e-mail to Ian Kelly (interstellar) (address idkk@idkk.com) and from this document's thesis and your (collective) antithesis we will be able to synthesize a better plan for this, our most exciting – and I believe necessary – adventure.

If nothing else, think about what name the ship would have. It will be a technologically complex Ark carrying a saving remnant of humankind away from destruction of its homeland to an unknowable far destination.

I would dearly love to travel in space, but I know I won't. I really want to live long enough to see men on Mars, but I probably won't[17]. If we want our children's grandchildren for many generations to continue survival, however, we absolutely must, as a species, move off this planet. The non-negotiable cost of not doing so is annihilation. The (monetary) cost of doing so is great – but, I believe, necessary. The cost of *not* doing so is greater than any other cost we have ever had to consider in the history of mankind[18].

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15 Since 9 is an odd number, how 10-to-the-9 can be *bi-* anything is beyond me!

16 "Whatever is said in Latin, appears to be profound."

17 I have even declared that my preferred place of dying would be on board a spaceship en route to Mars – even if I never got there: the going would be wonderful – so wonderful.

18 This has been quoted as an "ELE" – an Extinction Level Event – the highest possible grade of disaster, from the human point of view.

We simply have to make the effort[19] to get out there.

Per Ardua Ad Astra.

19 NASA’s motto is *Per Aspera Ad Astra* – by hope/through adversity to the stars. We need more than hope or dismay at adversity (*Aspera*) – we need effort (*Ardua*).

Possibility

“Everything that exists, exists in some quantity, and can – in principle – be measured.”

Preamble

This is consideration of the question “*Can we?*”. That is, we are asking whether it is possible to send humans safely from Terra to a star, or a planetary system around a star other than Sol, and (possibly) back again. Can we do it?

To answer this question we have to consider the other questions in more detail, but we can come up with a first layer of answers here. It is my opinion that we can do it. That is, I believe that it is possible – right now – to design and construct interstellar travel devices for humans. My belief systems, however, do not of themselves show that it can in reality be done – I have to justify what I am stating, and try to give some description of how it can be done, what it will cost, and when it can be done – the other main questions in this document.

As part of the first layer of consideration of the question “*Can we?*” we have to consider the distances involved, the time-scales involved, and what the (sketchy) designs could be for interstellar travel devices. We have to consider the physics that we know now – without inventing new physics – and the engineering that we know now – though we may have to assume some (reasonable) future development in engineering. We must not, at any time, assume any “Silver bullets” – inventions that make it all easy, or principals of physics not yet discovered which make (for example) faster than light travel trivial. We must assume the problem is hard, and face it accordingly. Let us see how hard …

Problem Size

This is not a small or simple problem. The distances are enormous, the logistics complex, the timescales long. The engineering is not obvious, and (at the very least) extremely expensive. We do not have any “Silver bullets” to make the problem simpler, quicker, easily tractable. I would have liked to assume just *one* “Silver bullet”, in the means of energy production (see page 66 below) – I would really, really have liked to – but even though this is something being currently researched – with great avidity – it is still too far-fetched[20]. We can *not* assume any magic breakthroughs – just hard slog, and error, and great cost, and long times, and social disagreement – all the things that have characterised large engineering projects from the Pyramids through the Great Wall and the Cathedrals and the Lunar landings.

If the solution of this problem is to be undertaken then we have to be ready for the costs. If we do not undertake to travel beyond Terra, however, we are doomed. Terra has a finite lifetime, and we are rather sure that we have about another five thousand million years[21] before Sol goes nova. That, kids, is The End – the end of the human race (unless, somehow, we have learnt how to survive in plasma – a rather doubtful prognostication!).

It is against this immensely high – and non-negotiable – cost of *not* solving the problem of interstellar travel that we have to consider the real costs of travelling. It is also against this very high abstinence cost that we have to measure the difficulty of the problem. I would suggest that the negative costs are so high that almost any expenditure is justifiable: if we don’t do it, we – the Human race – don’t survive. Period[i].

All of this is considered in more detail in the section on Costs (page Error: Reference source not found below).

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20 I do assume one “Copper bullet”, though – I assume that we will have achieved controlled nuclear fusion for our energy source (see page 76 below).

21 About $5.5 \cdot 10^9$ years or $[5.0 \cdot 10^9, 5.5 \cdot 10^9]$ (>95%) years (Ref: [Gott2001] and [JimL2003] *et al.*)

Distances

The distance of the nearest star to Terra is about 93 million miles. That star is, of course, Sol[22]. The next nearest star (*Proxima Centauri*), however, is about 4.5 light-years away[23] – or about 31 by 10^6 (the number of seconds in a year[24]) by 300,000 (the speed of light in kilometres per second[ii]) by 1000 (metres in a kilometre) by 4.5 (the number of light-years) metres (gulp!) – which is about $4.18 \cdot 10^{16}$ meters[25]. For a planetary system we have to consider up to 100 light years as the destination – about $5 \cdot 10^{18}$ meters – and probably more. We will – at the upper extreme – also consider distances of up to 1,000 light years – about $5 \cdot 10^{19}$ meters. Journeys of intergalactic distances (of the orders of up to millions of light years or $5 \cdot 10^{19}$ to 10^{21} metres and beyond) are *not* considered in this document[iii] - we are considering only what we could – just possibly – do: this is all science fact, not science fiction.

These distances imply very long journey times. We must assume (as physics teaches us) that faster-than-light travel is impossible. Faster Than Light (FLT) travel is science fiction – that's not what we need to have here. Indeed, getting to appreciable fractions of light speed is difficult. If we have very long periods of sustained acceleration we can get to very high speeds – acceleration at about 1*g* for a year gets you to about 80% of the speed of light, for example. But we have to justify being able to produce accelerations of this magnitude for time-scales of this magnitude

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22 That is about 8.5 light-minutes away – or $3 \cdot 10^5$ [kilometres per second of *c*] $\cdot 10^3$ [metres per kilometre] $\cdot$ 8.5 [minutes] $\cdot 6 \cdot 10$ [seconds per minute] = $3 \cdot 8.5 \cdot 6 \cdot 10^9$ metres = $1.5 \cdot 10^{11}$ metres. The true distance is [$1.496 \cdot 10^{11}$, $1.53 \cdot 10^{11}$, $1.47 \cdot 10^{11}$] metres (mean, aphelion, perihelion) [Ref: Meyl1958].

23 Ref: [Brit1988]

24 One way to remember this is "*there are π (pi) by 10 to the seven seconds in a year*", or "*there are π (pi) seconds in a nano-century*".

25 One light year is about $9.46 \cdot 10^{15}$ metres – for "back of envelope" calculations you can think of this as being $1.0 \cdot 10^{16}$ metres – a one followed by sixteen zeros.

before we can consider journeys at such high speeds. Even in space the mass of the projectile is directly related to the force required for a given acceleration.

Let us (initially) assume that for the trip we are considering we need to travel 100 light-years. Let us also assume ~~(and this will be later justified)~~ that it is possible to achieve continuous accelerations of up to 0.1*g*, or 1 m/s/s. *If* we had the energy (which is enormous) and *if* we could keep up this acceleration for $2.5 \cdot 10^8$ seconds or under 3000 days, then we would reach a speed of 0.85*c* – that is, 85% of the speed of light. This means that (with the times required for acceleration and deceleration) the outward journey time is over 140 years. This is rather a long time, and does mean that we have to construct a vessel (or vessels) that can carry breeding colonies. (We are *not* assuming that we will find the engineering to produce suspended animation – as beloved by so much science fiction!). Remember – we accept that this is a hard problem, and has to be faced accordingly.

This initial assumption of scale has to be considered against the background – and very real – possibility that we are designing a machine for *eternity*. That is, there is no final stopping place for the interstellar ship, and the inhabitants need support for all the time they can reasonably be expected to survive. The engineering and biological and sociological (etc.) systems must be designed with extremely long times in mind. Systems that last for, say, a hundred thousand years are not just different in *scale* from those designed to last one or ten years, they are different in *kind*. I shall be assuming, in my final figures, that we are designing for a ship that works for at least one million years – and if we can achieve that, we may well have achieved the longest reasonably possible for humankind. After a million years will the travellers still be "human" as we recognise humanity? We cannot say.

Because of the various relativistic effects, it may be best to limit our speeds to under 0.5*c*, (half the speed of light), where there is a relatively small effect on the mass and time dilation caused by the motion. The standard multiplier of $1/\sqrt{(1-v^2/c^2)}$ (called gamma, γ, or the Minkowski Factor) (Ref: [Eins1955] and [Born1962]) is, for 0.5*c*, only about 1.15 (reciprocal is about 0.86). This makes only a small effect upon the energy required for acceleration, and upon the differences between the time-perception of the travellers compared to the time-perception of Terra. In fact, we are (for reasons of propulsion) likely to limit our speed to under 0.23c and much lower, which gives a gamma (γ) of only 1.0275.

I will present figures for two possible maximum speeds – 0.01c or one percent of the speed of light, and 0.001c or a tenth of a percent of the speed of light – both very high figures, but nowhere near what is described in Science Fiction[26].

26 And that's what Science Fiction is – *fiction*.

Sizes

Because we have to transport a breeding colony, there is a certain minimum size, below which we cannot sustain both (a) genetic diversity, and (b) the required mix of skills for long-term civilised survival. For the sake of this discussion we are going to assume that the base population[27] for the first, trial ship is 120,000 – we are going to set off with one hundred and twenty thousand people. We do *not* assume that the population size will remain static, but that we can support up to 500,000 (five hundred thousand – half a million) inhabitants / colonists / travellers in a single ship – or maybe even a million.

Other scenarios are possible – we could, for example, have a cluster of ten ships, each initially housing just 12,000 people, that set off in convoy. This is the same number of people, but in smaller ships. If these ships remained within ten million kilometres of each other[28] – 10^{10} metres – there could still be communication and exchange between the ships, but the chances of a single disaster's destroying the complete crew (*i.e.* the crews of all ships in the fleet) would be much reduced. "Cluster or singleton" has both engineering and psychological/social implications – but these are for consideration elsewhere. Henceforth (initially) we will consider only a singleton – one vessel. But we have to remember there are alternatives.

A single vehicle to transport over a hundred thousand people would have to be rather large. We assume in the first sketch design here that it is, at the very least, seventeen kilometres long by eleven kilometres in diameter, and that it is (roughly) cylindrical in shape. We go into a more detailed description later. The walls of such a vehicle would have to be "adequately" thick. Adequate for what? Well, adequate for *at least* a hundred thousand years of service, and possibly more (up to a million years). If we are considering distances of up to 1,000 light years, it is very much more than 1,000 elapsed years – possibly 10,000 elapsed years.

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27 the initial number of travellers.

28 1 AU is about $1.49 \cdot 10^{11}$ meters, so the spread proposed here for the ships is about one fifteenth of the distance between Terra and Sol – a goodly gap, but not too great to traverse.

That's a *lot* of heavy engineering! In this first design, however, that means that the outer walls themselves should be *at least* 25m thick, assuming that the construction material is nickel-iron (Ni-Fe). For a hollowed asteroid of greater size, for example, we could usefully – and easily – have outer walls that are over 100m thick. Indeed, for a "large enough" asteroid (one whose diameter is over 75 km.) we could have an outer wall of 1 km. thick. And for the upper timescales we are considering (one million years) even 1 km. might not be enough – we will be considering several kilometres of wall.

These sizes may seem ridiculously large – but we are talking about a *very* long journey, and of incarcerating generations of people for their complete lifetimes. And we are talking about extreme (though rare) stresses – see the section on engineering, and meteor impacts. Since, also, an interstellar vehicle would have to be built in space – it cannot be built on Terra and then launched – the extremely large size need not be an obstacle – provided that the basic materials for its construction can be easily found in space already, and do not have to be all transported there.

Other sizes are possible – larger and smaller. The smaller our initial crew, the more we risk losing of our human culture. The larger, the more populous, we make our initial vessel, then the larger and the more various the tranche of life that we are preserving. I have spent some time working in the city of Exeter, Devon. This is a delightful place, well set, beautifully contained, with a wide variety of humankind in it. Within this city – which has about 120,000 inhabitants – there are experts on mathematics and music and cooking and mediaeval carving and calligraphy and bee-keeping and medicine and psychology and engineering and building and public hygiene and school-teaching and cheese-making. Within the city there are players of Bridge and Chess and Go and Football and Rugby and Cricket. There are church organs and their organists. There are theatres with actors, writers and readers of poetry, artists, scientists, and sundry folks of many and varied skills all supporting each other and the community. If we could transport a body of people this large on our interstellar ship, then we would have preserved a very great deal. If we could transport an even larger initial number we would have an even greater genetic mix, and the possibility of preserving (by transporting) the arts of, say, cake decoration, fine wood carving, lute-making, hedge-laying, computer design, mathematical research, philosophy, Flamenco dance, contortion, librarianship … and thousands of other arts and practical bodies of knowledge that might not exist in a smaller population, and which (in a smaller crew) might be considered superfluous.

And these example lists (above) show how we have to choose our skills carefully – librarianship, fine wood carving, hedge-laying and computer design are, in fact, important skills to preserve, and expertise on mediaeval carving and playing Go not as important.

Effects

Part of the measure of possibility is the measure of effect. There are two effects – the effects upon the participants (and their descendants) and the effect upon those who do not participate – the rest of the human race.

This is a project that can be undertaken only if we – collectively – decide it is worthwhile. The costs, after all, are huge – both financial and social. I argue in this document (and I am not the first, nor the last to so argue) that the costs of *not* making this adventure are even greater – the certain annihilation of the complete human race. I am (at the time of writing) 60 years old. I know that I, personally, will not take part in interstellar travel in any physical way. But I will die more contented if I can be persuaded that humankind will at least *try* to save itself from destruction. Interstellar travel is part – but only part – of what is required. Also we need to be more forward-looking, more respectful of others (including the future generations), less greedy, more careful, more caring. We need to be – as all the religions have told us for a long time – more loving.

Engineering

Preamble

We need to consider:

- What are the possible designs for a ship? (See “Possible Designs” page 42 below)
- How can a ship be powered? (See” page Error: Reference source not found below)
- How can a ship be transported – what is its mode of propulsion? (See “Propulsion” page 78, and “Speed” page 81)
- How can a ship be constructed? (See “Construction” page 47 below, and “Getting There” page 87 below)
- What do we do with a new planet if we get to one? (See “” page Error: Reference source not found below)

This section, then, is concerned with the hardware engineering aspects – “everything you can kick”. The biological and social questions are considered in other sections.

This is an engineering project – so this section on engineering is (inevitably) one of the longest.

Possible Designs

Here my engineering ignorance shows through. I am going to suggest two possible designs. The first – for lack of a more subtle suggestion – is a long cylinder with rounded (hemispherical) ends. The second design is a hollowed-out asteroid.

Cylinder

This cylinder would rotate about the long axis of the cylinder, to give pseudo-gravity (centripetal force). The direction of motion would be along the long axis of the cylinder, so that any acceleration effects are in a constant direction (and the floors could be sloped[iv] to compensate for this.

This design gives an obvious location for the application of thrust, and for a “collecting scoop”, to gather space-material (of which more anon). This is also an easy design to illustrate in calculations.

For all the apparent advantages of a structure like this, it would be impossibly costly to construct. The matter for building it would either have to be lifted from Terra (costly in energy) or found already in space and processed there – perhaps using Luna as a materials source, and taking advantage of its low “gravity well”. If we are going to house 120,000 people[29] at the density of the 23rd densest country currently on Terra – Netherlands – which is 392/km^2, then we need an area of at least 120000/392= 306 km^2.

If we are constructing this as the interior of a single cylinder (the extreme, worst, case) then from the formula $2\pi rl$ for the area (where r is the radius and l the length), then we need a cylinder about 17.5 km long, and 5.6 km radius (ignoring the area of end caps) – and this is just the “bio-dome” section for the initial crew. If we were to consider using the density of France (110/ km^2), and a final population of 750,000 (three-quarters of a million), then we would have to start with a bio-dome cylinder of internal area $7.5 \cdot 10^5/110 = 6818$ km^2 implying a cylinder of perhaps 110 km long by 10 km radius. Such a long cylinder (width:length::1:5) might flex, so a more stubby shape (shorter, but wider), or a multi-layer structure might be considered.

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29 An initial 100,000 would quickly become 120,000 – and we have to design for many more than this.

If we consider (in the first sketch design) the cylinder to be 10,000 metres long, and 2,000 metres in diameter then it has a total surface area of[30] about $1.256 \cdot 10^8$ m^2 (again, ignoring the caps). Atmospheric pressure is about 14 lb/in^2, or about 14/2.2 *kg* per $(2.54)^2$ cm^2 or about 1 kg/cm^2. This is about 10^7 g/m^2 or 10^4 kg/m^2 Thus from atmospheric pressure alone we have to consider a total of about $1.25 \cdot 10^{12}$ *kg*. Note this is 10^4 kg/m^2 above any other strength required.

The pseudo-gravitational pressure of the contents may be assumed to be the equivalent of a column of water 500*m* high over each point. This is a mass of $5 \cdot 10^5$ *kg*. If we add ten times the atmospheric pressure this gives $6 \cdot 10^5$ kg/m^2 or 600 tonnes per square metre.

If we multiply this by three, to give a reasonable margin of error, we get about $1.8 \cdot 10^3$ tonnes per square metre. Allowing 1*cm* thickness for each tonne[31], we have $1.8 \cdot 10^3$ *cm*, or (minimum) 18 metres – just to withstand the basic pressures[32]. Hence the suggestion of the minimum skin thickness of 25 metres, with (possibly) 50 metres in places. (As we have observed earlier, even greater thickness – very much greater – would be used if hollowing out an asteroid.)

With an overall density of 2.5 (a not unreasonable figure: see Ref. [Brit2001]) this means that the mass of the skin alone, at 25 metres thickness, is $7.81 \cdot 10^{12}$ *kg* or about $7.81 \cdot 10^9$ tonnes or about 7.81 thousand million tonnes.

But this is a lot of construction from raw materials – and it still does not allow for all the matter that will have to be ejected as the rocket exhaust in propelling the ship.

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30 $2 \cdot \pi \cdot d \cdot l = 2 \cdot 3.141 \cdot 2000 \cdot 10000 = 1.256 \cdot 100{,}000{,}000 = 1.256 \cdot 10^8\ m^2$

31 For those of you brought up with old-fashioned imperial measures, 1 tonne = 1 metric ton = 1,000 *kg*.

32 I am aware that there a non-linearity in the thickness/support ratio in reality – but this choice gives a safe estimate. And we do want the interstellar ship to be safe!

Hollowed Asteroid

All of the above leads us to suppose that perhaps we should look to another source of large, coherent masses in space, which could be fashioned into ships, and which do not involve constructing, from small components, such large structures.

So the potential second design is to (partially) hollow out an existing asteroid.

If we compare the mass of our first sketch (the cylinder) with the mass of known asteroids, *215 Kleopatra* has a mass of at least $8.6 \cdot 10^8$ million tonnes or $8.6 \cdot 10^{17}$ *kg*. (see Ref: [USNO2004] which gives $(1.0 \pm 0.1) \times 10^{-12}$ solar mass, [Brit1988] gives the solar mass as 1.99×10^{30} kg., hence implying *215 Kleopatra* has mass of about 2.0×10^{18} kg.) which is a factor of more than 10^5 greater than this.

Some of these asteroids, in natural orbit between Mars and Jupiter, can be quite large. For example *1 Ceres* is about $8.7 \cdot 10^{20}$ kg. in mass, and more than 930 km. in diameter[33] and there are numerous (hundreds) known asteroids that are larger than a 100 km. diameter sphere. This is likely to give us larger ships, that are easier to construct. There is, already, enough construction matter up there.

For all designs, the thickness of the outer skin has to be able to withstand:

- the internal pressure of the atmosphere, and
- the pseudo-gravity, and
- the longitudinal thrust, and
- reasonable lateral thrust, and
- the expected impacts (up to a reasonable limit) during the journey, and
- the gravitational/tidal effects experienced in the gravitational field of a nearby star or planet,

and

- the ship has to be to withstand this for at least a hundred thousand years – and more, as we are considering

33 Ref: [Hami2004] *et al.*

extremely long journeys.

In fact we should be considering even longer – much, much longer periods. Planning for a hundred years is hard. Planning for a thousand years is something we rarely do. For this project we should plan for ten, fifty or a hundred thousand years – something we have never done. But – collectively – we *can* do it. Now, kids, set your minds on a *million* years.

There is also a lot of stuff that wants to bump into us. The Earth (Terra) grows in mass by at least two hundred tonnes (two hundred thousand *kg.*) per day (Ref: [Aste2004], which quotes 300 tonnes per day – a substantially larger figure than we are using here) from the meteoric dust and particles it accumulates[v]. This is partly because the Earth (Terra) is a gravitational sink, attracting matter to it, and it is reasonably large, compared to our ship. The ship, though, will still suffer impacts – few because of gravitational attraction, but many by happenstance. And these impacts, even if they are from rather small particles, will be at extremely high relative velocities. Being hit by a bullet that travels at 2,000 km. per hour (which is 555.55 m/s) is one thing – but being hit by a bullet that travels at 2,000 km. per second is quite another. And that sort of relative velocity is perfectly feasible.

Remember that kinetic energy is proportional to the square of the velocity – so the relative energies of these two projectiles is not 3600:1 but 12960000:1 – not $3.6 \cdot 10^3$:1 but $1.296 \cdot 10^7$:1. If we envisage moving (ultimately) at 0.1*c* that is about 30,000 km. per second – striking an encountered, stationary, bullet-sized object at that relative speed is equivalent to $\approx 3.0 \cdot 10^{10}$ or about thirty thousand million times as powerful as a bullet of the same mass. Ouch.

Hence I suspect that we need to think of a skin much thicker than intuition initially suggests. I propose a skin of at least 10 km. Yes, ten kilometres – 10^4 metres. We need to make more detailed estimates of (a) what the probabilities are of being hit by objects of various sizes, and (b) what the relative velocities of the ship and the impacting object are likely to be, and (c) what degree of shell strength is required to withstand what degree of impact. Once these estimates have been made we will be better able to choose the skin thickness.

When a bullet (or other projectile) hits its target, the entry hole and the exit hole are very different. The entry hole tends to be small, and similar in shape to the projectile. On passing through the outer skin of the target both the target and the projectile are damaged, and energy is transferred. Hence the exit hole (if there is one) tends to be larger and more diffuse.

Construction

The techniques of construction depend upon the detailed engineering. The main question which has the greatest influence is:

- Is there one vessel or many vessels? (Cluster or Singleton).

One hollowed-out asteroid and ten nickel-iron asteroids in convoy are very different engineering tasks.

Cluster of Iron Ships

Simplicity

This seems to be a set of smaller problems than the single ship – each ship is its own nexus of engineering problems, and the cluster of ships is a cluster of these. And despite the title, there is no specific need for the ships to be of iron – though nickel-iron alloy may well turn out to be (a) plentifully available in space, without having to be transported from Terra, or some other deep gravity well, and (b) adequately strong, and (c) adequately durable (remembering the specialist long-term meaning of "adequate" in this context).

But it is *not* simpler than a single ship: it is the same as a single ship – but with the solution repeated a number of times. A cluster is not an avoidance of complexity.

There are sociological considerations to be taken into account for clusters of ships: there must be cooperation, not conflict between them; there must be a means of interchange between them; they must not be too close together, so that some could avoid disasters that overtake others, and so on. Some of this is discussed elsewhere in this document. Here – in this section – we are concerned only with the building of the ships.

Building such ships would be a lot more "fiddly" (and possibly more energy expensive and more time-expensive) than hollowing a single asteroid – but it would allow more choices to be made. For example, one ship could be desert, another could be humid, another could be tropical, another temperate, another arctic.

Substance

I have suggested in the title "Iron", but the body of a ship may be of anything that is strong enough – any mixture of materials. As we do not want to lift huge quantities of matter from the bottom of the gravitational well which is the Earth (Terra), but use readily-available materials, we may well be persuaded into using nickel-iron (Ni-Fe) from some M-type asteroid(s) that we "capture". Ni-Fe is strong. Given the absence of corrosive substances (on the outside of the ship) we do not have to be too concerned about external corrosion (rusting, oxidation). The inside, however, will be warm, oxygenated and damp – the sorts of climates and conditions human being like to live in – and we do have to be sure that the hull does not rust through from the inside. Remember we have to design for a long period of time – a machine that lasts just a year, or just a century is very different from one designed to last millennia.

There will have to be means of transferring energy within the ship. This may be radiant energy – which means we need glass or transparent plastics, or current energy – which means we need conductive substances (*e.g.* copper, gold or steel, etc.) and insulators (*e.g.* rubber or plastic or waxed paper etc. – whatever is appropriate).

We have to be able to grow plants within the ship – and hence we need a good deal of organic matter. Some of this can be manufactured *in situ*, by living organisms fixing the elemental or inorganic compounds they are fed. But we cannot perform transmutation of matter, changing atoms from, say iron into carbon. That is, we will have to ensure there is enough carbon, and nitrogen and oxygen (etc.) to support the large life-mass (biome) we are proposing.

From the section on biology, this means we need 2E+7 kg (20,000 tonnes) of carbon, $1.5\cdot10^9$ kg (1.5 million tonnes) of oxygen etc. (see the table 195), which means a total of half a million tonnes of organic base to be transported to the ship(s) before they start (assuming that much of the hydrogen and oxygen can be gathered from the asteroid rocks themselves). **<<<VERIFY THESE FIGURES ON COMPLETION<<<<**

Size

There is a minimum size for a ship. That size is controlled by three things (i) the stability of the internal biome, and (ii) being large enough to allow the inhabitants to have a reasonable life, remembering that this is the *only* environment that they will have, and (iii) being large enough to support a crew from which a balanced human population can descend. Thus these criteria are Stability, Variety, and Quality.

It is size that dictates a lot of the engineering difficulties. Unfortunately, a large size is a requirement. A small biome is not stable. A small environment would not allow a large enough population to be sustained – a population large enough to maintain the engineering and culture and development of a worthwhile human environment. My opinion is that (initially) 10,000 people is the very minimum population that we should consider. The upper limit is constrained only by the engineering – from the point of view of this essay we will start by assuming it to be just 500,000 people. This gives us a broad band for initial consideration.

A population of, say, 100,000 to 120,000 gives us the flexibility of a small city like (for example) Exeter – which would allow us to transport from Terra a wider variety of our skills and learning. This (I suspect) might not be the size of our first IT project – but it *is* a size we should (at some point) consider.

Since this is a project which concerns saving the whole of the human race (as a species) we have to consider more that one IT ship – a minimum of three (IMHO) or perhaps "one per century" (with no numerical upper limit) until we run out of Terra's resources (or come to our senses).

Structure

As part of our engineering we will also have to try things out. New bits of engineering have to be tested. It might be reasonable, for example, to take a smaller structure (such as of the size of, say *3554 Amun* or *1864 Daedelus*), and put it into a Pluto orbit, at (say) 20AU. This would be a reasonable test-bed for the large-scale engineering required for the real ship.

A prototype in distant Solar orbit would allow us to check out the technology for very long-term habitation in closed, artificial environments. It would allow us to make modifications – perhaps radical ones – whilst still relatively "close" to Terra – although 20AU might not normally be considered "close", it certainly *is* close compared to the ultimate distances for the interstellar ship.

Such a prototype would not be cheap, if by "cheap" you mean "costing only a small amount of money" (the British English meaning of the word), but would (IMHO) be a really necessary first run. Discovering that this or that system does not work is not something you want to do at more than 100 AU from Terra, and moving away from it at an appreciable fraction of light-speed.

This prototype would, in itself, be a worthwhile scientific base, allowing us to measure aspects of space not easily accessible from close to Sol. It would also allow us to measure the effects of long-term cultural isolation upon groups of technically sophisticated people – but there is more discussion of that in a subsequent section of this work (see page **???** *et seq.* below, and also Ref. [Hall2001], [Karu2003]) **<<<<< INSERT PAGE REFERENCE**

Location

Of course the location is in space! But where exactly? If we are hollowing an asteroid, then we have to start in that asteroid's orbit. When finally fitting out the ship prior to final launch, however, we may make use of more distant orbits – to get a feel of what it is like to be out of touch of Terra for a long period.

One suggestion, mentioned previously, is to put the ship into a Pluto orbit, or an even more distant orbit at (say) 40 AU. It is reasonable that the *starting* location is in the asteroid belt (between 2 and 3 AU from Sol) – if we are hollowing an asteroid, rather than building from scratch, this is the *necessary* starting location[34] - though we may find a usable Aten or an Amor or an Apollo, which intermittently may bring us closer than 2 AU. We may also consider a *testing* location, much closer to Terra: there is a stable orbital point in the shadow of Terra, about 1,500,000 Km (930,000

34 Unless, that is, we decide to use something like *433 Eros* or *3753 Cruithne*.

miles) further out. This is one of the Lagrangian points[35], and it has the advantages of being:

- close to Terra – it would not take long to get there and back, during the building phase
- in (partial) shadow – it is a good test location to determine whether the internal systems actually work, with the chance of fixing them from Terra before the ship sets out.

The mean distances of the major planets from Sol, in AU and meters are:

Planet	AU	Metres
Mercury	0.387	$5.8 \cdot 10^{10}$
Venus	0.723	$1.082 \cdot 10^{11}$
Terra	1.000	$1.496 \cdot 10^{11}$
Mars	1.524	$2.28 \cdot 10^{11}$
Jupiter	5.203	$7.783 \cdot 10^{11}$
Saturn	9.540	$1.427 \cdot 10^{12}$
Uranus	19.18	$2.8696 \cdot 10^{12}$
Neptune	30.07	$4.497 \cdot 10^{12}$
Pluto[vi]	39.44	$5.9 \cdot 10^{12}$

A light-year is about $9.46 \cdot 10^{15}$ metres[36], which is about $6.32 \cdot 10^{4}$ AU (over sixty-three thousand Astronomical Units)[37].

Singleton

One Hollowed Asteroid

Again, there is no necessity to choose just one asteroid – we could consider a cluster of these – but each one is the same engineering

35 Point L2. See http://en.wikipedia.org/wiki/Lagrangian_point

36 For "back of envelope" calculations you can call that $1.0 \cdot 10^{16}$ metres (1 E16 m).

37 If we take the radius of the Solar System to be 100AU then the 200AU from (notional) edge to edge is only 1.5E11x200=3E13 metres – or just over 1 light-day.

task as the others.

The substance from which an asteroid is made depends upon the asteroid – there are “light” (low density) ones and “heavy” (dense) ones. I have to be advised on this, but I presume that we want to use a “heavy” (dense) asteroid as this would (a) be stronger – given the timescales involved a very important point, and (b) give the availability of more mass to jettison (for propulsion) and (c) would also, by its density, offer better protection to its inhabitants (the travellers) against radiation[vii].

All of the discussion for the cluster is true for the singleton – the size, the substance, the structure and the location have the same requirements.

We do not know how many asteroids there are in total, but the estimate (made in [WIKI<<<]) of the number of asteroids (N) exceeding diameter D is:

D	N	D	N	D	N
100 m	25,000,000	5 km	90,000	200 km	30
300 m	4,000,000	10 km	10,000	300 km	5
500 m	2,000,000	30 km	1,100	500 km	3
1 km	750,000	50 km	600	900 km	1
3 km	200,000	100 km	200		

In the following table, those asteroids (planetoids) whose names have been stated in bold are worth considering as the source of a possible base from which an interstellar ship could be constructed. Those whose names are represented in *italic* would (perhaps) make good short-distance bases, and transit camps. The others are either too large (for the moment – though we may adopt more powerful technology in the future) or too small – too cramped for long-term use, or too sparse and lack sufficient density. Some asteroids are, under any circumstances, too small to support the crew sizes necessary for stable biological survival.

.<IMAGE OF ASTEROIDS>.

Some Asteroids

For those asteroids where I have not yet discovered a recorded mass, I have assumed densities of 1.6 g./cm^3 – which is rather light – for asteroids where I do not know the type, and 2.5 for S-type asteroids. Thus, any estimated masses will be (at the lower limit) too small[38]. The masses are calculated using the formulæ: $m=4\pi r r^3/3$ or $m=\pi r d^3/6$ for single r (radius) or d (diameter), or $m=4\pi r r_1 r_2 r_3/3$ or $m=r/6$ for r_1, r_2, r_3 (radii) or d_1, d_2, d_3 (diameters), and r is the density. The column headed "Density" indicates the density value used in the mass calculation, if there is a density known: if the figure is in parentheses, then it is a guess, rather than an observed value.

Note that this table is just a tiny selection from the known small objects in the Solar System – there are more than 500,000 known asteroids (over 275,000 of them have permanent reference names and numbers), plus the comets, and planetary moons. This table contains just those about which I personally know most – this is not a definitive list. We can make our final selections based upon (a) size (what can our engineering cope with), and (b) density (what is the stone made of), and (c) location (its existing orbit and velocity), and (d) what costs we are prepared to endure – always remembering the ultimate cost of *not* trying – the total annihilation of humankind – *i.e. Can We? Would it Work? Where is it?* and *What would it Cost?*

From http://www.nineplanets.org/asteroids.html (accessed 20070915) "*Several hundred thousand asteroids have been discovered and given provisional designations so far. Thousands more are discovered each year. There are undoubtedly hundreds of thousands more that are too small to be seen from the* Earth. *There are 26 known asteroids larger than 200 km in diameter. Our census of the largest ones is now fairly complete: we probably know 99% of the asteroids larger than 100 km in diameter. Of those in the 10 to 100 km range we have catalogued about half. But we know very few of the smaller ones; there are probably considerably more than a million asteroids in the 1 km range.*"

38 Volumes have in general been calculated as if for spheres. No attempt is made here to take into account any great irregularity of shape, where that is known, except to use the known diameters in the calculation.

The table below also contains some planetary moons – the names without leading identifying numbers. These (I think) should not yet be considered as ships, as they would involve overcoming other gravitational wells in getting them to move (the pulls of Jupiter, Saturn, etc.). There are plenty of other rocks around!

Asteroid Name and Number, or Moon Name[39]	**Sizes (diameters, km.)**	**Mass (kg.)**[viii]	**Distance (in AU) from Sol**[40]	**Density g/cm^3, Class**[41]
4581 Asclepius	0.3	(2.67E+10,3.53E+10)	1.02	
6489 Golveka	0.35 x 0.25 x 0.25	(1.83E+10,2,86E+10)		Q
1915 Quetalcoatl	0.4	(5.36E+10,8.37E+10)		SMU
1566 Icarus	1.3	(1.84E+12,2.87E+12) [1.0E+12]	1.07	SU,Q
3554 ***Amun***	2.1	(7.75E+12,1.21E+13)		M (1.6)
1864 **Daedalus**[42]	3.1	(2.49E+13,3.90E+13)		Sr
3753 **Cruithne**[ix]	5	(3.01E+13,4.70E+13)	0.997 to Sol or 0.3 from Terra	Q
4179 Toutatis[x]	4.6 x 2.4 x 1.9	(2.08E+13,2.30E+13) [5.0E+13]	2.51	S,Sq [2.1]

39 For a longer version of this table, see page Error: Reference source not found in the appendix.

40 This is the mean orbital distance, where known (and quoted in the literature). For some objects – with very eccentric orbits – the perihelion and aphelion will be very different.

41 C = Carbonaceous, S = Silicacious, M = Metallic – but for greater detail see page ?? below.

42 We seem, as a culture, to remember Icarus – the one who failed to fly, because of the heat of the Sun, melting his waxen wings, and forget Daedalus, his father, who (being a good engineer) succeeded. “Daedalus” is an auspicious name for an engineering venture!

Asteroid Name and Number, or Moon Name	**Sizes (diameters, km.)**	**Mass (kg.)**	**Distance (in AU) from Sol**	**Density g/cm^3, Class**
Trinculo	10	(8.37E+14,1.30E+15)		
Leda	16	5.68E+15		
M1 Phobos	19 x 21 x 27	(1.09E+16,1.12E+16)		1.95 (S?)
951 **Gaspra**	19 x 12 x 11	(2.10E+16,2.36E+16) [1.0E+16]	2.20	S (1.6)
Calypso	26 (34 x 22 x 22)	(1.37E+16,2.15E+16)		
Ophelia	32	(2.74E+16,4.28E+16)		
847 Agnia	32	(2.74E+16,4.28E+16)	2.78	S (1.6)
863 Benkoela	32	(2.05E+16,2.74E+16)	3.20	A (1.2)
433 **Eros**	39 x 13 x 13	(8.28E+16,9.21E+16) [6.69E+15]	1.45	2.67 [2.4] S
243 **Ida**[43]	48 x 24	(3.61E+16,3.90E+16) [1.0E+17]	2.86	2.7 [2.5] (S?)
Prospero	50	(1.04E+17,1.63E+17)		
43 **Ariadne**	65	(2.30E+17,3.59E+17)	2.20	S (1.6)
253 Mathilde[44]	66 x 48 x 46	(9.19E+16,1.06E+17) [1.033E+17]	2.64	1.3 C (1.4)
25 Phocaea	78	(3.97E+17,6.46E+17)	2.40	S (1.6)
80 Sappho	82	(4.61E+17,7.21E+17)	2.29	S (1.6)
Juliet	84	(4.95E+17,7.75E+17)		
Pandora	84 (114 x 84 x 62)	2.20E+17		
Prometheus	91 (145 x 85 x 62)	2.70E+17		
17 Thetis	93	(6.73E+17,1.05E+18)	2.46	S (1.6)

43 *Ida* is known to have a tiny natural satellite of its own, called *Dactyl.*

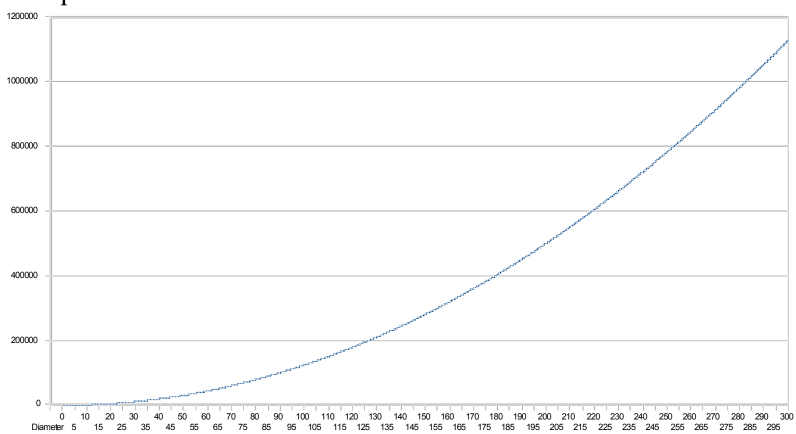
44 "Mathilde's interior must, quite literally, be full of holes". (Ref: [Beat2000]).

Asteroid Name and Number, or Moon Name	Sizes (diameters, km.)	Mass (kg.)	Distance (in AU) from Sol	Density g/cm^3, Class
26 Proserpina	99	(8.12E+17,1.27E+18)	2.65	S (1.6)
Thebe	100 (100 x 90)	7.77E+17		
40 Harmonia	111	(1.14E+18,1.28E+18)	2.26	S (1.6)
Epimetheus[45]	115 (114 x 108 x 98)	5.59E+17		
Phoebe	115 x 110 x 115	4.00E+18		2.3
588 Achilles	116	(1.30E+18,2.04E+18)		D (Lagrangian L4)
12 Victoria	117	(1.34E+18,1.51E+18)	2.33	S (1.6)
2060 Chiron	180 x 148	(3.30E+18,3.71E+18) [4.0E+18]	13.63	B
6 Hebe	185	(5.30E+18,5.96E+18)	2.42	S (1.6)
7 Iris	203	(7.00E+18,7.88E+18)	2.38	S (1.6)
215 **Kleopatra**	217 x 94 x 81	(1.34E+18,2.16E+18)	2.76	M
Phoebe	220	4.00E+18		2.3
92 Undina	250	(1.30E+19,2.04E+19)	3.18	
16 Psyche	264	(1.54E+19,1.73E+19)	2.92 [2.619]	1.6, M
704 Interamnia	350	(3.59E+19,5.61E+19)	3.06	
31 Euphrosyne	370	(4.42E+19,6.63E+19)	3.14	
Miranda	472	6.59E+19		
4 Vesta	570 x 460	(2.08E+20,2.21E+20)	2.36	3.5

45 The secret of fire was revealed to men (according to legend) by Prometheus. The gods, therefore, hated Prometheus, but loved his brother, Epimetheus. Epimetheus is hindsight: Prometheus is foresight. We now, the engineers, are the openers of Pandora's twenty-first century box.

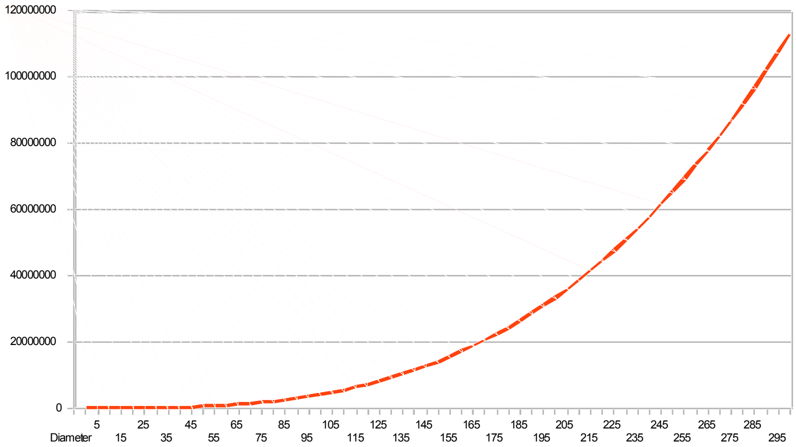
Asteroid Name and Number, or Moon Name	**Sizes (diameters, km.)**	**Mass (kg.)**	**Distance (in AU) from Sol**	**Density g/cm^3, Class**
		[3.0E+20]		[3.3] V (U)
2 Pallas	570 x 525 x 482	(2.11E+20,2.41E+20) [3.18E+20]	2.77	2.8 [3.2] U
1 Ceres	960 x 932	(8.97E+20,1.17E+21) [8.7E+20]	2.76	2.05 [2.7] C
Quaoar	1280	(1.75E+21,2.74E+21)	43.37	
Io	3632	8.93E+22		
Callisto	4820	1.08E+23		
Titan	5150	1.35E+23		1.88
Ganymede	5262	1.48E+23		

There is a simple relationship between diameter and volume. For an arbitrary density of 1.0 (density of water) then the weight of an asteroid in mega-tonnes is shown in the following graph. For “small” asteroids, of 50 *km*. diameter, or smaller, the size/mass diagram has the familiar exponential shape – and it is the same shape for all sizes of asteroid:



A very large asteroidmay well be composed of more than one kind of rock, which adds to the engineering complication. A small asteroid may well be all of one rock type The types of rock we currently believe exist on asteroidsrange from loose carbonrich black rubble (*e.g. 253 Mathilde* a C-type) to silica-rich stone (*e.g.*

951 Gaspra an S-type) to heavy metallic (*e.g. 215 Kleopatra* an M-type), though until we go up there and look at a number of them *in situ* we cannot be sure – the long-distance observations and the fallen meteorites are not a wide sample. Moreover, stony asteroidsin particular are likely to be covered in fine dust – the pulverised results of continued impact – the so-called regolith[46]Ref: [Answ2005b]. This will limit the use of such an asteroid, as much of its mass may not be bound to the stone itself, but "free floating". We would have to find a technique of "binding" such as asteroid into a coherent (and strong[47]) shell.



If we make the middle assumption that we can find (by inspection – lengthy and expensive inspection, but not difficult) one or more asteroids of density in the range from 2 to 5, composed of some iron-rich rock (M-type asteroids), then we can make our first sketch design. We do not *have* to use an M-type asteroid, as one of the S-types may well be massive enough, and well enough

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46 There is a possibility that surface regolith, if deep enough, could act as a protective barrier to minor impacts from small objects encountered. It can not, however, be considered as part of the ship's structure when calculating tensile strength (*e.g.* resistance to internal atmospheric pressure).

47 Strength is mandatory – the ship does not have to be pretty in order to survive. It *does*, however, have to be strong. Surface loose regolith would either have to be bound firmly, or collected (as part of the initial ejecta), or ignored in the calculations of tensile strength.

structured (without having to be initially reinforced) for our use. Note that some of the moons of Uranus and Neptune are believed to consist almost entirely of water ice, or methane and frozen nitrogen: we most assuredly do *not* want an asteroid of this composition for our exercise.

In the table I have highlighted *3753 Cruithne*, *951 Gaspra*, *433 Eros*, *243 Ida*, *43 Ariadne*, *215 Kleopatra*, *3554 Amun*, *17 Thetis* and *1864 Daedalus*. All of these have positive points for them – though at different sizes, and appropriate to different centuries, at different realisable costs.

For the purposes of this design I will take the asteroid *433 Eros* – which is about twice the size of Manhattan Island – 39 by 13 by 13 km – though I am not suggesting that it is this particular asteroid that we *have* to use, but merely going from its known properties. There must be others like it around – and of a wide range of sizes. *433 Eros* is not perfect, insofar as it is an S type (stone), rather than an M type (metal), but its high density (>2.6) means it is fairly solid (unlike *253 Mathilde*!). If we really want upwards 100,000 inhabitants we might have to choose something larger (such as, say, *243 Ida*, *17 Thetis* or *215 Kleopatra*). *433 Eros* will be a little crowded – but not too bad.

For our second or third (or ninth or tenth…) ship we might choose *17 Thetis* or *215 Kleopatra*, and slowly (very slowly – over centuries – this is not a quick project!) move up to *4 Vesta* or *2 Pallas*[48]. The asteroids *3554 Amun* - which is only 2.1 km across – or *1986 DA* (just 2.3 km in diameter) might make good space-stations or dropping-off points. But here all of these choices are speculation – our descendants will choose on the basis of the engineering they have available at the time. And there are a lot of choices.

Outline Design

There is great fun to be had in setting out possible designs for a

48 There are a few thousand lumps of rock out there, any of which could (potentially) be used as a ship. The long-term survival of the human race is guaranteed only if one or more of these ships survive: the more ships we have, the better the chances. For analogy, see [Clar1988].

ship. The ideas put forward here are simple first hints, and are not the definitive answer. They are put forward merely as food for thought, and to show that the real solution is actually possible – if we just think about it.

Wasp Nest

A wasps' nest is a complex, multi-celled mechanism, constructed in several layers, with a sealed (well, *almost* sealed) outer covering, and within a multi-layered structure, a hollow centre. This is (perhaps) the ultimate design that we could consider for the ship. If we take an initial asteroid, then we have the possibility of hollowing it out, keeping the integral outer skin, and constructing numerous internal cells (small ones are rooms and halls, and large ones could house fields and parks, etc.).

I am well aware that a real wasps' nest is constructed upwards from nothing, and what is being proposed for the IT ship is the reverse – hollowing out from the already-existing. See Ref: [Ther1995], [Dur2005] and – for fun – [Boug1892].

Comfort

Mankind, for his comfort, requires both large and small spaces. Without access to large spaces we feel cramped. Without access to small spaces we feel intimidated. We need our houses and our parks, our cosy bedrooms and our expansive areas in which to run. What we cannot offer, on a spaceship, are the large wilderness areas to explore. It is a truism to say that the whole journey is itself an exploration – and we have to remember that the travellers will go out of their cocoon very rarely indeed. Each outside trip is costly – not in terms of energy, but in terms of matter.

And the ship has to be comfortable. There are a large number of people that are going to be living on board for their whole lives – we owe it to them (our descendants[49]) to make the ship comfortable.

49 Who are – potentially – the ultimate survivors of the Human race.

Self-sufficiency

The ship has to be self sufficient. This is not easy. We cannot supply the ship with a million years' worth of anything, and in the long future give a sigh of sorrow when we know that thing has run out. We have to ensure that everything the ship uses, everything the ship needs – absolutely everything – can be manufactured aboard the ship, from substances and products already aboard the ship, using skills that will continue to be passed down, generation to generation, aboard the ship.

That's the way Terra works: we do not have, on this planet, a thousand years' supply of wheat, for example. What we have is a couple of years' supply of wheat, and the (stable) means of creating more. We have a few years' supply of paper, and the knowledge of how to grow trees and convert them in to paper. We have a few years' supply of computing equipment, and the (complex) machinery and knowledge for creating more. This, on Terra, is true of everything.

We also have some salutary tales from history that shows what happens to a group of people when they destroy the means of production of some commodity. Easter Island, for example, switched rapidly from being a fishing to a farming community when they had cut down their last tree, and could no longer makes ships from which to fish. We no longer know how to play certain musical instruments (or have had to regain the knowledge from first principals), even though we have physical examples of those instruments, because the skill was not passed down, and was lost (*e.g.* theorbo, viola d'amore[xi])[50].

So self sufficiency must cover air, water, food, building materials, paper, engineering materials, medical products, machines, musical instruments, books, films (movies), CDs, computers – and so on. This means that every engineering system we introduce must be self-sustainable. We cannot send repair teams or spare parts up from Terra – it's *all* going to have to be done on board.

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50 And even with an enormous amount of text in hieroglyphics, reading that too was a skill that was lost, and had to be reconstructed.

Duplication, Triplication …

Now there will be accidents and tragedies. It is inevitable that something important will explode or burn or collapse or rot away. So it is essential that we do not have just one of anything. The minimum number of copies of everything we want to preserve is three. If there are just two copies then it is possible for a single accident to destroy both of them – consider the possibility of an external body piercing the shell and reaching the other side of the ship, possibly piercing that side as well. In that single accident two areas of the ship would have been destroyed – and if this happened to line up on the two copies of something important, then it will have been lost to the ship for ever. Similarly, one layer of the ship (if it is organised in shells) may be poisoned or become hazardously radioactive. If both copies are on that layer, both copies may be destroyed or simultaneously inaccessible. Thus copies must be on different layers (in different shells). Although it is fiction, Arthur C. Clarke's *Rama* books [Clar1972] do mention triplication as being the essential minimum.

Preservation of Information

Part of the engineering is the preservation of information about the engineering – it's no good our making a wonderful ship and sending it off, if the travellers have no idea where things are or how things work. It's not just about engineering that we have to preserve information – we will want to preserve art and history as well.

On Terra all the techniques we use are subject to decay. We know a fair amount about the culture in Egypt three thousand years ago because of their records – but not everything: records have been lost and disfigured. Suppose that the writings of 18th Dynasty Egypt (c. 1550-1292 BC) were not documents about kings and wars and taxes, but instead instruction manuals and design documents and repair information form machines upon which our lives depended. We would now be in a sorry state – yes, there is a lot that has been preserved, but a huge amount – the majority – that has been lost, and much of what we have we no longer understand.

Information can be recorded in memory, and passed on as recitation, and it can be written on stone, on paper (and papyrus and velum, etc.), and it can be saved to CD or recorded on magnetic media or in quipu knots. None of these methods – or any other method – is eternal, and we have to ensure that the methods the ships use are supported by a strong enough backup procedure. CDs, for example, have to be copied from time to time, to preserve their contents – and CDs rely, for their reading, upon machinery. Paper-written information needs only human eyes for access, but paper too has a finite lifetime (it decays and discolours, the edges get brittle and sections of documents are lost, the text gets written on and disfigured[51]). Typically, for the *really* important stuff we should be looking at making new copies every 50 years (there is more study to be done here to make more secure estimates). And the process of copying must be one which is accurate. This may mean bringing together two or more copies of the information for purposes of comparison – and that increases the danger of data loss in a single incident.

[I have been told that there is a ratio of Nitrogen to Oxygen at which human life can be sustained, but at which paper does not burn. (I *think* this is about 14% oxygen rather than ≈21% we are used to). This might help in the preservation of libraries – but is slightly dangerous: loss of consciousness and death can take place in excess Nitrogen, without the victim having felt any discomfort. An excess of carbon dioxide is uncomfortable – raises a danger signal – but an insufficiency of oxygen does not.]

Simple techniques are the ones which last the longest. Simple information is the sort that is preserved the longest. The technical information used within a Bronze Age civilization was passed on by word of mouth. The Bronze Age was complex and rich with many strands – metalwork, pottery, politics and warfare (social organization of large groups), trade, cooking, social organization of small groups (families and villages), language, poetry, art, architecture – all of these existed. The knowledge of how to make a pot was passed on by one generation of potters to the next, by demonstration.

The knowledge about how to build a nuclear power plant, and how to deal with an accident in one, is not something that can be so

51 Doodles in the margin, and underlining words in a book have very different effects if there are thousands of copies of the book, or only one.

easily passed on. It is not a small body of information that can be recited, and it is not something that can be practically demonstrated *unless* (if we choose to use nuclear power) we have a sufficient number of plants whose construction is staggered in time. Suppose, for example, that in the first century of constructing the ship we build one new plant every ten years. If each plant has a lifetime of about 60 years then we will gradually settle into the state of always having six productive plants, one being built, and "several" being managed as they decay. The exact number of "several" depends on the techniques being used, and the degree of radioactive risk that we are prepared to accept. With this sort of pattern we *can* pass on the information about building power plants by demonstration. But this is rather a large number of nuclear power plants – in 2004 on Terra, for example, there were fewer than 500 of them.

So one method we can consider is that of making everything so simple that it is obvious. It may not have been obvious to think up the techniques, the initial design may have been very complex indeed – but once it's done even a Bronze Age community could sustain it. Let me give an example of two machines that are obvious once you have them, but complex to think up: a vacuum coffee percolator, and the Moka coffee percolator. Each of these has two chambers, with water initially being put in to the lower chamber. The seal between these two chambers has to be strong. Each of these has an unsealed (open) upper chamber, into which the water will be forced from below by pressure of its boiling. In each case the raw ground coffee is placed in the middle: for the vacuum percolator simply loose in the top chamber, on top of a grid or filter, and for the Moka percolator in a cage or basket. And in each case, heat is applied from below to boil the water. From here one their operation differs.

For the Moka percolator, the water is boiled, and the pressure in the lower chamber forces the water up through the cage or basket of ground coffee and on up through a central tube from which it drips down in to the top chamber. The water passes just once though the ground coffee, and cannot return to the source of the heat. When all the water is in the top, the heat may be removed, and the coffee poured for serving from the top container. Air can get in to the lower chamber through the central tube, so there is no pressure difference.

A: Bottom chamber which contains water. When this is heated, pressure from the steam pushes the water through B and into C

B: Basket containing ground coffee

C: Collecting chamber for coffee

For the vacuum percolator, the water is boiled, and similarly forced up in to the top chamber, where it meets the ground coffee. But there is no central tube allowing air back in to the lower chamber. When the source of heat is removed, and the lower chamber cools down, it now contains a vacuum. This sucks the coffee-flavoured liquid from the top chamber back through the filter in to the bottom chamber. At this stage you have the choice of reapplying heat, and re-percolating, or of just removing the top chamber and serving the coffee from the lower chamber.

These are simple devices to make and to describe – but their invention requires knowledge of pressure and vacuum and how pressure changes with state-change from liquid to vapour. To use these coffee percolators you do not need that knowledge: to invent them (and, possibly, to repair them) you *do* need that knowledge.

Because of the limited number of travellers, and because of the fragility of information transfer, we need to make as many of the ship's systems as direct as these coffee percolators.

Power

How can an interstellar ship be powered? How much power is needed?

We know that chemical fuels simply will not work – we have to allow for a very long lifetime, and any reactions would simply leave behind waste matter – which the ship would carry with it. There is no possibility of carrying enough chemical reactants for a long journey.

Also we must not assume we are going to find some new principle of physics that will allow us to get energy "by magic" – without effort, in huge quantities. We have to assume that we already know the basic physics with which we are going to operate. I would love to discover viable cold fusion – but I am not assuming it here.

So we have the possibilities of nuclear reaction – fission and (hot) fusion. These are certainly sources of huge amounts of energy – but whether they are large enough remains to be seen -–we will be discussing that in some detail.

But first we must determine how much power[xii] is needed.

How Much Power?

There are two main uses of power on the ship: sustenance and movement. That is, there must be enough power to run the ship (keep it warm and bright, keep it airtight, keep it comfortable for upwards of a hundred thousand people for ten, a hundred, five hundred millennia and more), and also there must be enough power to move the ship through space. We have to keep it warm, and we have to keep it moving.

Any work inside the ship, which is not pushing the ship forward, will warm the ship[52]. This includes generating light, electricity, radio signals, and mechanical work in tilling the land, building habitations, cooking food, and heavy engineering work such as excavation. For the internal power requirements, all we have to calculate is "how much power is needed to keep it warm?". Well, it's a bit more complicated than that, as we shall see.

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52 Strictly: any work exerted inside the ship and not directly dissipated by acceleration or extra radiation will warm the ship.

For our illustrations of different sizes we will assume that we are using one of the six asteroids *433 Eros* or *243 Ida* or *43 Ariadne* or *17 Thetis* or *20 Massalia* or *215 Kleopatra*.

Sustenance Power

We shall consider how much energy is needed to retain the temperature of the body, and we can compare this to the amount of energy received by Terra from Sol, which is about 340 $W.m^{-2}$. That is the incident Solar energy – the absorbed energy is, currently, about 240 $W.m^{-2}$, the rest being reflected.

Name	**Size km.**	**External Area m^2**	**Radiation Loss (total)**	**Sustenance per 1000 yrs.**
433 Eros	39 x 13 x 13	1.59 E 09	5.05 E 11 W	1.59 E 22
243 Ida	48 x 24 x 24	3.62 E 09	1.15 E 12 W	3.62 E 22
43 Ariadne	65 x 65 x 65	1.33 E 10	4.21 E 12 W	1.32 E 23
17 Thetis	93 x 93 x 93	2.72 E 10	8.61 E 12 W	2.71 E 23
20 Massalia	151 x 151 x 151	7.16 E 10	2.67 E 13 W	8.41 E 23
215 Kleopatra	217 x 94 x 81	6.41 E 10	2.03 E 13 W	6.39 E 23

For radiant energy loss, we consider how much energy is radiated by the body, if its internal temperature is average 15º C. = 288 Kº. We assume that the external temperature is 4 Kº – interstellar space is not at zero degrees. This boils down[53] to about 3.7E2 $W.m^{-2}$ or about 370 watts per square metre.

53 For all radiant bodies we may apply the rule:

$$W = e(T) \cdot s \cdot A \cdot T^4$$

where W is the power, s is the Stephan-Boltzman constant (of value $5.670 \cdot 10^{-8}$ $W.m^{-2}.K^{-4}$), A is the surface area of the body in m^2, and T is the temperature difference in degrees Kelvin. e(T) is a temperature-dependant correction factor – (WOLOG) we can take this to have its worst value – the value 1 – so that the formula reduces to sAT^4 or $4\pi r^2 T^4$ for any body similar to a sphere of radius r. T (the temperature difference in degrees Kelvin) in our case is 284, hence T^4 is 6.50E9. So sT^4 is 6.15E9 x 5.670E-8 $W.m^{-2}$ = 36.85E1 or (roughly) 3.7E2 $W.m^{-2}$.

So when we do the calculations, it turns out that we have to provide the same amount of energy, per square metre of external surface, as Terra receives from Sol, per square metre of external surface. That's not really surprising, is it? If we provide any more energy, then the ship will heat up over time: if we provide less energy, the ship will cool. The Earth is the temperature it is because of the radiation it receives from the Sun. When the Sun radiates less, we get colder; when it radiates more we get warmer.

This is something we should remember on Earth too, as all the extra energy we are creating is either conversion of Solar energy stored geologically – we are drawing from the piggy-bank of heat – or it is fresh, new energy the Earth did not receive as incident radiation. All of this energy use must – inevitably – heat the Earth.

The surface of the Earth is the temperature it is also because of the amount of energy the Earth reflects. The Earth's albedo is about 0.3, which means that about a third of the energy that hits the Earth is reflected back. This is the difference between Incident Solar Energy (about 340 W/m^2) and Absorbed Solar Energy (about 240 W/m^2). If we make the Earth darker it gets warmer, make it paler and it gets colder.

To get the sustenance power in the table above, we multiplied the radiation loss (in Watts) by 3.15 E 10 (roughly the number of seconds in a thousand years) to get the number of joules required per thousand years.

Transportation Power

Transportation power depends upon the mass being transported, and its acceleration. For simplicity we will calculate just the power required to accelerate the ejecta to the speed of 0.001c (one thousandth of the speed of light, so about 300 km/s or 3 E 5 ms-1. The energy is the total kinetic energy of 0.5 mv^2

Name	Size km.	Density	Volume m^3	Mass kg.	Transportation energy, joules
433 Eros	39 x 13 x 13	2.5	3.45 E 12	8.63 E 15	3.88 E 26
243 Ida	48 x 24 x 24	2.5	1.45 E 13	3.62 E 16	1.67 E 27
43 Ariadne	65 x 65	1.6	1.44 E	2.35 E 17	1.04 E 28

	x 65		14		
17 Thetis	93 x 93 x 93	1.6	4.21 E 14	6.74 E 17	3.03 E 28
20 Massalia	151 x 151 x 151	2.7	1.80 E 15	4.86 E 18	2.19 E 29
215 Kleopatra	217 x 94 x 81	2.5	8.65 E 14	2.16 E 18	9.73 E 28

The volume of *433 Ariadne* is about[54] 1.44 E 14 m^3. If we assume the density to be low (1.6) this gives an initial mass of 2.35 E 17 kg. For 1 kg accelerated to 1 m/s we have to provide 1 joule, so for 1 kg accelerated to 0.001*c* (or 3 E 5 m/s) we have to provide 3 E 5 joules. We can eject only about 50% of the initial mass – we do not want the honeycomb (wasps' nest) to collapse. So if we multiply the mass of each asteroid by half (which is the amount of ejecta) and 3 E 5 (joules per kilogram we have to expend on the ejecta) we will get the transportation energy for that asteroid, assuming that we really do eject stuff at that fabulous speed.

[In the table above we have shown both $0.5mv$ and $0.5\ mv^2$ for v=3 E 5 m/s or about 0.001*c*].

Total Energy

Name	Mass kg.	Transportation energy, joules	Sustenance per 1000 years, joules
433 Eros	8.63 E 15	3.88 E 26	1.59 E 22
243 Ida	3.62 E 16	1.67 E 27	3.62 E 22
43 Ariadne	2.35 E 17	1.04 E 28	1.32 E 23
17 Thetis	6.74 E 17	3.03 E 28	2.71 E 23
20 Massalia	4.86 E 18	2.19 E 29	8.41 E 23
215 Kleopatra	2.16 E 18	9.73 E 28	6.39 E 23

The transportation energy is a great deal less than the sustenance energy. As we can see (from the table above) it always takes more

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54 From $4\pi r^3/3$ where $r \approx 32.5$ km. ≈ 3.25 E 4 m is 143790 km^3 or about 1.44 E 14 m^3. Note that all the figures in these tables are approximate as we are not yet certain of the dimensions or of the physical characteristics of the asteroids.

energy to sustain the ship for a thousand years than for the total transportation: the transportation energy is expended only once, but the sustenance energy is required all the time.

These are very high energy requirements. Is there any way we can reduce them?

Yes, there is. In the case of transportation, we can travel slower, and take longer to get wherever we are going. In the case of sustenance, we can reduce the overall radiation of the ship by insulation. Let's look at these.

Insulation

The Dewar ("Thermos") flask is one well-known household object that can reduce the heat loss of its contents by a factor of at least a hundred. This works by reducing the transmission of heat by conduction and convection, by isolating the inner section from the outer with a double-wall, containing a vacuum. The radiation losses are reduced by reflective coatings on the inner walls of the vacuum chamber. This provides a relatively thin wall which is a very poor heat conductor.

Making the whole of the ship a Dewar flask is somewhat extreme – and we do not need to save on thickness of insulation – we have kilometres of thickness we can use. We can make the ship's shell a poor heat conductor by inserting large pockets of insulation padding. This padding might be ceramic lattice, as used on the Space Shuttle insulation tiles [REF], or the equivalent of wire-wool or glass fibre. Whatever insulation method is chosen, it has to be consistent with keeping sufficient tensile strength in the shell, hence there is bound to be some conductive loss to the outermost surface, and hence radiation loss. No strength, no ship. Too much heat loss, no ship. These have to be balanced.

Even better insulation is provided by doing this operation twice – Dewar insulation inside Dewar insulation (the "double Dewar"). This is already the principle used for the storage of liquid Helium – the inner Dewar container is surrounded by liquid Nitrogen, within the outer Dewar container.

We shall take the insulated radiation loss to be one thousandth of the uninsulated loss. That is, the heat loss will be just 0.35 W/m^2

rather than about 350 W/m^2. This gives the heat loss as:

Name	Sustenance per 1000 years, joules	Sustenance per year, joules
433 Eros	1.59 E 19	1.59 E 16
243 Ida	3.62 E 19	3.62 E 16
43 Ariadne	1.32 E 20	1.32 E 17
17 Thetis	2.71 E 20	2.71 E 17
20 Massalia	8.41 E 20	8.31 E 17
215 Kleopatra	6.39 E 20	6.39 E 17

Slower Speed

Travelling slower uses less energy – but only up to a point. If there is a final destination for the ship, then we have to consider the extra sustenance energy required because of the longer journey time, which will adversely offset the saving made by travelling slower. For each reduction in speed there is a break even time: if the journey takes longer than this, then it would have been cheaper in energy to travel faster to that destination. This break-even time is twice the transportation equivalent in years. That is, if the transportation energy is equal to *n* years sustenance, then any journey taking longer than *2n* years is more energy efficient at a faster speed.

Name	Base Transportation energy, joules	Insulated Sustenance per 1000 yrs.	Transportation equivalent in years (approx.)
433 Eros	1.29 E 21	1.59 E 19	81,000
243 Ida	5.43 E 21	3.62 E 19	150,000
43 Ariadne	3.52 E 22	1.32 E 20	270,000
17 Thetis	1.01 E 23	2.71 E 20	370,000
20 Massalia	7.29 E 23	8.41 E 20	865,000
215 Kleopatra	3.24 E 23	6.39 E 20	507,000

The larger the ship, the more time we have to offset against the transportation energy, which is an advantage. The following graph plots, for these six asteroids, the final velocity against the break-even time for sustenance. It also indicates the minimum velocity that absolutely has to be attained – the escape velocity from the solar system. This velocity is an absolute – it does not matter what the size of the ship, that is the minimum velocity we must reach. In these calculations we are measuring all velocities relative to Sol. Remember that the ship will already have its orbital velocity around Sol, which is a portion of its velocity that we may not have to provide.

[DIAGRAM]

If we look at 215 Kleopatra, then for 100,000 years we need about 6.5 E 23 Joules for sustenance, and another 3.5 E 23 Joules for transportation. So we need to find 1 E 24 Joules, spread over the hundred millennia. If this energy is supplied by the fission of plutonium, then we would need (at current efficiency rates) more than ten million metric tonnes of plutonium to supply this – which is rather a lot to start off with!

~~So that means we have to find up to 5.5 2.0´10^{16} kg (about the mass of *951 Gaspra*), of which we are going to eject 50% at 0.8*c*, then we have to be able to supply about 2.9´10^{32} Joules over the ten millennia, just for transportation. *[This implies that the mass of fissionable uranium for just this portion of the energy requirements, assuming 1% efficiency of fission, is 2.9´10^{32}/(3 ´10^{7}*3´10^{7}) kg. = 3.2´10^{19} kg – which is a thousand times the original mass of the body we are proposing to transport. A problem.]* Even if we eject 50% at only 0.01*c* we still have to provide at least 4.0´10^{30} Joules – which still requires a greater fissionable mass than the original total mass.~~

<<RECALCULATE ALL THIS KELLY!>> ~~[1.5*10^{13} W for 6*10^{9} people – but unevenly spread – giving ?? per person per year. In the USA 3.3*10^{13} W for 3*10^{8} people, giving ?? per person per year Hmm these figures don't match! (even without doing the division) Also we have the statistic (from [Eart2007]) 7.8*10^{3} kg oil equivalent per capita per year USA – which seems to be a more reliable figure. Call this (rounded) 8 tonnes per head per year oil equivalent. 1 tonne oil equates to about 11.6*E10^{3} kWh or 41.8*10^{12} joules. So for the USA we have about 3.3*10^{14} joules per head per year. If we make the – unjustified – assumption that this will be the amount required on the ship, then we will have in the~~

first year 3.3*10^{19} joules, and assuming bounded population growth, peaking at 500,000 we will have **10^{23} joules** in the first millennium and **10^{26} joules** over the first million years. This is much less than our other calculations!]

[From the formula for kinetic energy of $\frac{1}{2}mv^2$ where (in our example) m=1.0´10^{16} kg, and v=2.4´10^{8} m/s we have that the minimum energy is 0.5*2.4*2.4*1.0´10^{32} = 2.88´10^{32} Joules]

[Radiation heat loss appears to be 1.87´10^{4} watts/m^{2} and if we consider something with an area of 7.3´10^{22} m^{2} – the size of *951 Gaspra* – this gives us 1.372´10^{27} watts in radiant energy loss – I suspect *this* calculation is wrong!]

[Radiation loss seAT^{4} <<sigma epsilon A T to the fourth>> where T is in K° and A is in m^{2} and e is 1 for perfect radiator (we assume 0.5 here) and s is 5.6703´10^{-8} watt/m^{2}K^{4} – Stephan’s Constant. For outside temperature of 1 K° and internal temperature of 300 K° on a body of area 7.3´10^{22} m^{2} we have 3´10^{2} * 3´10^{2} * 3´10^{2} * 3´10^{2} * 7.3´10^{22} * 5.67´10^{-8} * 0.5 = 3 * 3 * 3 * 3 * 7.3 * 5.67 * 0.5 ´10^{22} = 1.676 ´10^{25} watts (two orders of magnitude smaller than before) = 1.676 ´10^{19} megawatts = 1.676 ´10^{11} terawatts. Hmm. This is smaller than before – but still horrendous!]

[My intuition – which is not reliable – suggests that 10 kw/m^{2} would be adequate, as a general energy input. This gives 1´10^{4}*7.3 ´10^{22}=7.3´10^{26} watts as the heat loss. If the heat loss per m^{2} were only 1 watt, then the result would be 7.3´10^{22} watts heat loss for *951 Gaspra*.]

[To accelerate 1 kg from rest to 0.8c in 1 second is an acceleration of 2.4´10^{7} metres per second per second, and requires 2.4´10^{7} Newtons. To do this to 1.0´10^{16} kg requires a total of 2.4´10^{23} Newtons, over 10,000 years. If this is evenly spread, then it is spread over about 3.1´10^{11} seconds, giving us just 0.77´10^{12} or 7.7´10^{11} Newtons per second. ??Joules?? !!Watts!! This involves over point seven terawatts- seven hundred gigawatts – which is rather large. If we go for an acceleration to just over 0.1c, or 3.1´10^{7} metres per second, then we have 3.1´10^{22} over 3.1 ´10^{11} seconds, or 1.0´10^{11} watts – just one hundred gigawatts continuously for 10,000 years. Compared to the previously calculated heat loss this is small – but it is none the less huge!]

[If we consider the lowest required energy as being $mv^2/2$ where *m* is the mass ejected, and *v* is the velocity of ejection, then if we take a mass of 1.0´10^{16} kg and an ejection velocity of 0.1*c*, or 3.0´10^{6} *m/s* (the speed of light being about 3.0´10^{7} *m/s*) then the minimum transport energy is 1.0´10^{16} x 9.0´10^{12} / 2 » 4.5´10^{28} Joules. 1 megaton = 4.2´10^{15} Joules so we have about 1.07´10^{13} megatons. At 100% conversion, 1kg of matter release about 9.0 ´10^{14} Joules (from $e=mc^2$). So according to this calculation about which I am very dubious we would have to convert 4.5 ´10^{28}/9.0´10^{14} kg to get the energy or about 5.0´10^{13} kg. I suspect I have got something *badly* wrong here! Yup I got the speed of light wrong!]

[If, instead, we assume that our ejection velocity is “only” 0.001*c* a thousandth of lightspeed, or about 3.0´10^{5} m/s then the minimum transportation energy for the same mass as before is 1.0 ´10^{16}*9.0´10^{10} » 9.0´10^{26} Joules, which is 9.0´10^{26}/4.2´10^{15} » 2.1 ´10^{11} megatons. That’s still a lot!]

[If we take the ejection speed to be a “mere” 10,000 m/s or 1.0´10^{4} ms/, then the transportation energy would be 1.6´10^{16}*1.0´10^{8} » 1.6 ´10^{24} Joules » 1.6´10^{24}/4.2´10^{15} megatons » 6.6´10^{8} megatons. This is more reasonable but still huge. It also means that we are releasing energy over a period of 10,000 years at 1.6´10^{24}/(1.0 ´10^{5}*3.1´10^{7}) Joules per second » 3.0´10^{11} Joules per second. That means we release one megaton every 4.2´10^{15}/3.0´10^{11} seconds » 1.4´10^{4} seconds » 3.9 hours or more than six megatons every day. Hmm.]

[If we consider the initial and final momentum, and assume – *pro tem* – that the body first accelerates for 5000 years, and subsequently decelerates for 5000 years, then at the start time the velocity is zero, at the 5000-year point, the velocity is *v* and the mass is ¾*m* where *m* is the initial mass. This means that the momentum of the body, at 5000 years, is ¾*mv*, and that – <u>on average</u> – the amount of momentum change per second (and hence the amount of energy required per second) is, for a body of initial mass 2.0´10^{16} kg – the mass of *951 Gaspra* – about 1.5´10^{16}*v*/(5.0 ´10^{3}*3.1´10^{7}) » 3.2´10^{5}*v* Joules per second. The average over the deceleration phase is the same, per second – but the distribution is different. In each case, the maximum effort is expended at the start

~~of the period, for a given fixed rate of acceleration/deceleration. This means that for one megaton – or 4.2´10^{15} Joules – it takes 4.2´10^{15}/3.2´10^{5}*v* » 1.31´10^{10}/*v* seconds. If the achieved speed (*v*) is about 0.001*c*, or 3.0´10^{5} m/s then this is 1 megaton every 1.31´10^{10}/3.0´10^{5} » 4.3´10^{4} seconds » 11.94 hours – or just over 2 megatons per day, or (3.2´10^{5}*3.0´10^{5}) = 9.6´10^{10} Joules per second.]~~

[Formulæ: $v=u+ft$: $s=ut+½ft^2$: $v^2=u^2+2fx$: $f=du/dt=d^2s/dt^2$: kinetic energy=$½mv^2$: momentum = mv : force P=m.dv/dt]

Over a period of 10,000 years with a speed of about 0.001*c* (3.0´10^{4} m/s) after 5000 years, this means the minimum quantity of energy required is:

Usage	Calculation	Energy
Transportation	(Paragraphs above)	1.0´10^{10}/s
Sustenance		7.3´10^{26}/s
Total		7.3´10^{26} watts/s = joules

And since we are considering a very much greater timescale – one million years (but not accelerating the whole time!) – we have to reconsider these figures. **<<RECALCULATE KELLY!>>**

Fission

Nuclear fission is a “solved” problem. That is, we already know how to make stable nuclear reactors on earth that “burn” Uranium 235 or Plutonium 239. We have wide experience of these reactors, and can make them all kinds of sizes – from that small enough to power a submarine to large enough to power a city.

Fission reactors consume nuclear fuel. This fuel is, in statistical terms, rare on Earth, and expensive to mine. It would be possible to transport quantities of it into space, but we have to be sure that we have solved the safety problems in the logistics – we do *not* want tons of enriched Uranium released into the atmosphere in a shuttle disaster, for example.

[7.3´10^{26}=$0.01·m·c·c=0.01·m·3·10^{11}·3·10^{11}=m·9·10^{20}$, hence $m=7.3·10^{26}/9·10^{20}$ = 8E+5 kg/s <<<<CHECK UNITS which over

10,000 years is $3.1 \cdot 10^7 \cdot 10^5 \cdot 8 \cdot 10^5 = 1.75 \cdot 10^{19}$ kg U_{235} in total. This is about a tenth of the total mass of *Ceres*, or a hundred times the mass of *Gaspra*, just for the power source, and is completely unrealisable.]

[One kilogram of plutonium offers about $2.2 \cdot 10^7$ KwH of power, or is equivalent, under fission, to about $2.0 \cdot 10^7$ Kg of high explosive. 1 KwH = 1E3x3.6E3=3.6E6 Joules. 1kg Pl = 2.2E7x3.6E6 Joules = 9.92E13 Joules. Round this to 1E14 Joules. So for 1E24 Joules we need 1E24/1E14 kg = 1E10kg = 1E7 tonnes. Hmm – we have to start off with ten million metric tonnes of plutonium on board.]

If we consider that we are going to need **???** XXX for power over 100,000 years, that means as much as **???** kg. of enriched Uranium (or ??? kg. of U_{235}), assuming a 1% efficiency rate of mass/energy conversion[55]. For the interstellar ship, disposal of the spent fuel is easy – we just convert it into part of the ejected acceleration stream. Getting the fuel there is more problematical – if we do not discover natural Uranium already on the asteroid (or on some asteroid) then we have to transport is from Earth (Terra) – which involves the heavy safety considerations I have mentioned.

It would seem, given these figures, that we have to consider another means of acquiring energy.

Fusion

Fusion is much more efficient. This is not yet, alas, a solved problem. Although we can see Sol and other stars burning stably in the universe, we have yet to produce a stable nuclear fusion reactor. The only nuclear fusion reactors we can currently produce are inherently unstable – the H-bomb.

Stable fusion has been researched for many years, without as yet producing an effective and stable result. So we have to assume that there is something "difficult" about fusion that we have not yet discovered. Perhaps, for example, it needs at least 20g. externally for stability, or very large amounts of light or some specific atomic

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55 From $E=mc^2$ we have $9 \cdot 10^{16}$ per kilo at 100%, or just $9 \cdot 10^{14}$ kg m^2/s^2 at 1% efficiency. Current reactors are better than 1% - but worse than 2% efficiency.

mixture in the reactive mass. But we just don't know. We have tried, and are still trying (in China [REF<<<<]), to produce it in Tokamak and Zeta and Theta and Z-pinch … and many other names (for example. See [Answ2005a]), but we have not (yet) achieved stable fusion.

This is the one place where I make an assumption – the "copper bullet" (not as magic or as unobtainable as the "Silver bullet"). I am going to assume that we *will* achieve controlled nuclear fusion (hot fusion) and that this can be used as our source of energy for the ship.

Cold fusion – where nuclear fusion takes place at low temperatures – typically at room temperature – is something that we will not consider here. Without loss of generality, we can (for the moment) assume that it does not exist.

Sub-critical Nuclear Reactions

Current spacecraft technology does not use critical reactors, but relies upon sub-critical reactions. These cause heating without the possibility of criticality. These are less efficient that proper nuclear reactors, but are (it is said, by NASA) to be safer. See the references to RTG (Radioisotope Thermal Generators) (*e.g.* [Spac2002] and [Wiki2005b]).

There is, in the circumstances of the extremely large ships we are considering, no need (IMHO) to restrict ourselves to sub-criticality. And I am happy to allow "ordinary" nuclear reactors on large interstellar ship. (Ref: [Mit2005], and [Ans2000a/b])

Alternative Energy

There are many other possible energy sources that have been suggested. There are not considered here, either because they seem rather improbable, or use chemical sources (which we cannot use) or will not produce adequate output from portable quantities of fuel.

Conclusion

It seems that the best bet for the internal source of power for the ship, given our current level of knowledge, is (hot) nuclear fission. This implies that we have to be able to sustain the level of support technology to preserve the safety of such equipment – which has a sociological influence upon the ship, as well as an initial engineering (design) influence. It would be a *real* disaster were a nuclear plant to explode on a ship!

It would be more than helpful to perform some prior engineering development to achieve sustainable nuclear fusion, in that way that we can currently sustain nuclear fission. We *are* doing research – but not (IMHO) with sufficient impetus. Fusion would give us much more energy than fission, and be sustainable for longer – we know this, and mankind, even here on Terra, needs the energy.

Propulsion

The means of propulsion has been discussed in detail in many places. But there is no single solution that seems both feasible and attractive. The solutions include technology that has not yet been developed (enormously powerful space lasers, Bussard ram-jets, deuterium-pellet fusion bombs), or is limited by the technology that already has been developed, but is not powerful enough (extremely large rocket propulsion engines, sling-shot through a gravitational field).

I would like to suggest two alternative techniques that – to be fair – have not yet been developed, but look (to me) feasible. They are (i) ion propulsion, using fusion-generated power, and (ii) the "firecracker" technique of letting off small fusion bombs behind the ship, and moving forward on the blast (the Dyson effect, as researched in Project Orion. Ref: [Darl2003]). If we want to consider only already existing techniques, however, we have to choose some technique that allows us to (a) pulverise large quantities of matter very finely, and then (b) eject this matter in an extremely fast and directed stream. This technique – whatever it is – must not rely upon chemical energy, as that is (for this project) completely insufficient.

As a rule of thumb, in order to reach 50% of the speed of light, you have to throw away half your mass at the speed of light. Allowing for energy loss due to inefficiencies and heating, etc., we have to consider (in the limit[56]) throwing away 50% of our mass at 95% of

56 That is, the *upper* limit – the best we could possibly attain.

the speed of light in order to attain 45% of light-speed.

That's a lot of mass.

If we consider a large hollowed-out asteroid, for example, with an initial mass of $1.5 \cdot 10^{18}$ kg. (the mass of *215 Kleopatra*), we are going to jettison 25% of that to get to our maximum speed – which is therefore limited [absolutely!] to below 0.24*c* (less than a quarter the speed of light) at the very best – and another 25% in decelerating again (assuming that deceleration is required). In the case of 215 *Kleopatra* that would mean chucking away a total of $7.5 \cdot 10^{17}$ kg in two tranches – at maximum $3.75 \cdot 10^{17}$ kg for each tranche. To allow for flexibility, it would be well to allow for using another (say) $1.25 \cdot 10^{17}$ kg for initially unpredictable variations in direction and velocity. This brings the total ejected mass (in our example) to $8.75 \cdot 10^{17}$ kg, or (about) 60% of the total initial mass. If we were to allow for a skin 5 km thick, then the mass available (from *215 Kleopatra*) would be the rather larger $1.16 \cdot 10^{18}$ kg. If we wanted walls 10 km thick (which, IMHO, we do), then we still can discard $8.38{'}10^{18}$ kg (or 56%).

The mass to be ejected, the final mass of the ship, the speed of ejection and the speed of the ship are related by:

$$m_0 = m_1 e^{v/w}$$

where m_0 is the total initial mass (what we start with), m_1 is the total final mass (what arrives), *w* is the speed of ejection of the ejecta (how fast things are thrown out the back), and *v* is the change in velocity of the ship with respect to its starting velocity (how fast the ship is going). In this equation, Tsiolikovsky's Equation, *e* is the base of natural logarithms (about 2.7182818284590…).

The lowest speed we absolutely have to reach is escape velocity from the Solar System, and if we take our starting location to be in the Asteroid Belt, at about 3.0 AU from Sol that speed is 24 km./s (less than 0.0001*c*). The orbital speed at that distance is 17 km./s., hence the difference (the speed we have to add) is about 7 km./s. Because of the change in escape velocity as we spiral out from Sol we do not have to add as much as that in one go – we are not trying to escape in one single leap. Ultimately, though, that is the speed we have to achieve, at the very least[57].

To accelerate a mass of $1.0 \cdot 10^{14}$ kg. from orbital speed to escape speed in 3 years requires $2.25 \cdot 10^{9}$ Joules. If we were considering the rather larger *215 Kleopatra* we would need $1.93 \cdot 10^{13}$ Joules. This is just a few kilotons – very small by the standards of nuclear fusion. 1 megaton = $4.2 \cdot 10^{15}$ Joules. Thus $4.2 \cdot 10^{12}$ Joules is one kiloton, and $1.93 \cdot 10^{13}$ Joules is just 4.6 kilotons – about a third of the size of the Hiroshima bomb. Hence to accelerate to ten times that speed, or 300 km/s (0.001*c*) would take a few tens of kilotons (less than 50 kilotons) – an acceptable expenditure, if this is done within the Solar System, where the energy could be replaced by Solar radiation. And if we limit our acceleration to just this one tranche, then we have to consider only the energy for sustaining the ship thereafter.

Also we cannot (really) achieve such high ejection speeds as mentioned above – so we should, for our calculations, consider that we can achieve *at most* only 50% of light-speed (0.5*c*). In fact, we can probably – using current technology – achieve only 0.01*c*. That's a negative.

For a positive, however, we could help ourselves on our way initially by (perhaps) using gravitational acceleration. That is, we could pick up some of a large planet's velocity in a fly-by. If, for example, we steered our craft just the right distance from Jupiter, and picked up acceleration from the gravitational effect there, we could (arguably – though we have to check the figures) help ourselves on our way out of the Solar System "for free". We would have to be sure before we did this, though, that the tidal effects in the ship would not be destructive.

There is also no real need to escape from the Solar System in just three years, or ten years, or fifteen years – we have a ship designed for many millennia of use. We should accelerate only at an economically justifiable speed – remembering the only economy that concerns us here is that of the ship itself.

57 Or else we will simply fall back into the Solar system – perhaps after a very long time.

Speed

If we travel at appreciable fractions of the speed of light, then we have to consider the relativistic effects. These are not great if we stick to velocities below 0.5*c* (half the speed of light), as the following diagram shows:

In this diagram, the heavy line is the Minkowski factor – gamma (g), where the lower scale (horizontal) is expressed in percent of the speed of light. At 0.5*c* this gives a gamma of about 1.154 – which is just over 15% effect upon times and distances compared to our initial observer on Earth (Terra).

We are probably constrained to velocities in this range, until we learn some other physical techniques for acceleration. Remember that to attain 0.5*c* by simple rocket propulsion requires that we eject 50% of our mass at (or close to) 1.0*c* – an unattainable bit of engineering – hence we should (for the moment) suppose that our absolute maximum velocity is that which is obtained by ejecting 25% of our mass at 0.9*c* – which gives us a chance of slowing down again by ejecting another 25% of our initial mass. This limits our actual upper velocity to about 0.23*c* and gamma (g) to about 1.0275 – just 2.75% away from the "at rest" conditions.

In reality, using the engineering we currently know about and can reasonably predict, we should (at first) consider top speeds of under 0.1*c*, which gives[58] a gamma (g) of a mere 1.005 – only half a percent away from rest conditions. And even this "ten percent of *c*" is a very large figure, in terms of energy – perhaps unattainably large. If we can achieve only 0.01*c* (one percent of *c*) we can – for practical purposes – largely ignore gamma. We have been talking previously of a mere 0.001*c*, because of energy costs.

For reference, the value of *c* (the speed of light in vacuum) is $2.99 \cdot 10^{10}$ centimetres per second (more precisely $2.99792458 \cdot 10^{7}$ m/s – and more approximately – but more memorably – about $3 \cdot 10^{7}$ m/s. Note that $3 \cdot 10^{7}$ is within a tenth of a percent of the real figure). The speed of 0.1*c* is "merely" $3.0 \cdot 10^{6}$ metres per second [59]–

58 By the standard formula $1/\sqrt{(1-v^2/c^2)}$.

59 Or three thousand kilometres per second.

very fast in terrestrial terms, but not annoyingly fast for the apparent dilation of time. The "possibly attainable" speed of 0.01*c* is $3.0 \cdot 10^5$ metres per second – or three hundred kilometres per second.

As a complete aside – and nothing really to do with the discussion right here – the standard Newtonian Law of Gravitational Attraction states the value of the force to be:

$$Gm_1m_2/r^2$$

where G is the Gravitational Constant, m_1 and m_2 are the two masses, and r is the distance between the two masses. But considerations of Relativity force us to change this formula to (at least):

$$Gm_1m_2/r^2\sqrt{(1-v^2/c^2)}$$

where with angular velocity w we have

$$v^2=r'^2+r^2w^2$$

which is a rather more complex formula that we usually think about in this context. Our ship will be travelling – ultimately – at reasonable proportion of c and hence we will have to use the more complex formula (and all the other Relativity complexities too) in calculating the gravitational interaction of the ship with its surroundings, as it travels.

Remember that there is an absolute lower bound of (about) 24 km/s, which is the escape velocity from the Solar System. This is only about 0.0001*c* (but still rather large compared to what we normally experience in everyday life!).

Preservation of Matter

One fundamentally important point of the design – whatever design is chosen – is the preservation of matter. On Terra we do not consider the finiteness of our material resources. In particular we forget (too often until too late) that there are only a finite number of any give species alive, that there is only a certain amount of Gold or Uranium or clean air or fresh water, etc. On the ship, however, the problem is worse – very much worse. There really is a finite, and knowable, quantity of each substance available. We cannot add to what we start with – the ship cannot pick up matter en route[60]. If the ship loses any air, for example, it is lost for ever, and can never be regained. Thus each opening of an airlock door has to be considered for the tiny, even minute, amount of air that will be lost. If an airlock looses just one gram of air at each opening, then in a year at just two openings per day[xiii] we will have lost over two-thirds of a kilo of air.

Of course there will be accidents, but even if we ignore these, then in a thousand years we will lose 600 kilos of air just through this normal use of the airlocks. That's a lot of air – more than half a tonne. If the life of the system is (minimum) 10,000 years then we have to consider losing 6 tonnes of air alone through the airlocks. So (perhaps) we either have to limit – and limit severely[xiv] – the number of trips outside the ship, or we have to cope with this degree of loss[xv].

There is also matter that will be lost by intention – stuff we choose to chuck off the ship. This is the "rocket" exhaust, which propels the ship forward. This matter (the ejecta) may be up to half the initial mass of the body – the hollowed out material from the centre of the asteroid. This is matter that we are carrying for the sole purpose of throwing it away. We do not want this matter to be of "use" to us, and we have to be careful what we eject. The ejecta should be, for example, only the inert stone material, and not precious carbon or oxygen, without which life cannot be sustained.

So the ship has to preserve matter.

Self-Sustenance

And the ship has to be self-sustaining. That is, there has to be a stable biological system that can produce all the foodstuffs, support materials, technological artefacts and so on, then sustain a

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60 With two possible exceptions: the first is encountering particulate matter en route – meteorites – which are a hazards, and a source of danger to the ship, and the other is collecting interstellar gas. This gas exists, but is very thin indeed: interstellar space, inside a galaxy, is not *quite* a complete vacuum [REF]. Some studies have considered whether there is enough interstellar hydrogen to replace that lost by a ship's energy production – but the answer is not a simple one [REF].

technologically-dependent population. So there have to be areas in which crops can be grown, livestock kept, water creatures nurtured, and productive plants (such as trees) cultivated. There have to be woods and zoos and streams and lakes and parks and workshops and metal-works and hospitals and schools and libraries and control centres and computer repair areas and concert halls and theatres and dance halls and meeting rooms and quiet places and noisy ones. There has to be available to the inhabitants many (most?) of the things that are experienced by at least some happy people on Terra.

To be self-sustaining requires a lot of land. The rule of “forty acres and a mule” for each family is, perhaps, not too badly wrong. More exact figures are given in the section on Biology.

And to be self-sustaining requires careful considerations of safety. In particular, no one vital resource should be concentrated in just one site on the ship – a single accident could wipe out that complete resource. Nor should there be just two sites, but at the very least three. This then ensures that a single accident (for example, catastrophic penetration by an accidental crash) could not wipe out all of that resource, by its straight-line penetration of the ship. So three, or five or seven or nine (etc.) *non-collinear* duplicates and locations are required for every essential resource. So there is not just one library, but at least three, and so on. (For a detailed analogy, see [Clar1972]).

Similarly, we should never have all the ship’s inhabitants in one small space (or two small spaces) at the same time. If the ship is large enough there will be little temptation of this, except (perhaps) on occasions of special celebrations – but we do not want all the inhabitants annihilated – or annihilatable – by just one accident.

Asteroid

If we consider the initial ship to be hollowed from an asteroid that is (for example) 19 km long by 12 km across, starting with an average density of 2.2, then we can consider a series of (say) four concentric shells, arranged as in the diagram below.

The outermost shell is the thickest. This is the protection of the ship from the outside universe. This shell must be thick enough, and strong enough to

- sustain the physical integrity of the whole ship (*i.e.* keep it together),
- protect the interior from the results of (small) meteoric impacts (*i.e.* keep things out),
- carry the pressure ("weight") of the interior (*i.e.* keep things in)[61],
- contain the internal atmosphere, and withstand its pressure (*i.e.* keep the atmosphere in),
- help support the stability of the overall structure (*i.e.* stop it flexing or wobbling too much).

The structure inside the outmost shell is again a series of nested shells. Each of these has the same requirements as that for the outer shell. The innermost shell, however, encloses the largest volume on the ship – that of the central cavity. The innermost cavity is the "huge space" for the travellers – their largest park or largest farm or largest area of exploration or development. The innermost cavity is also that from which the ejected matter will be dug during the journey. The journey will begin with this section full, or almost full, and as the journey continues the central section will be hollowed out and turned into high-speed rocket exhaust. The ship will, as it were, "grow" an inner hollow during its life.

The outer shells have higher pseudo-gravity (from the rotation of the ship)[xvi]. The outermost shell could be used for storage – so as not to expose the humans to the highest gravity fields, and to put more "things" in between the people and space, between the people and incoming radiation.

The central axis is the thickest of the supports, and the only one that must be straight. The other supports keep the shells a fixed distance apart, and separate the shells into smaller sections. Each of these sections should be (potentially) airtight, to help minimise loss in the event of accident. The central axis, however, is that to which the impulse engine will impart propulsive force, and around

61 Note that we *do* have to have some gravity on the ship, both for convenience and to sustain the natural growth of most Earth life-forms.

which the whole ship body will rotate (in sustaining the pseudo-gravity).

The supports and major separation structures must be so placed that the body does not, overall, have any destructive modes of vibration. This is simply that we do not want the structure to “ring like a bell”, nor to be liable to flex itself to destruction. This is a usual – but computationally non-trivial – consideration in the construction of large freestanding structures[xvii].

In the previous diagram, the shading of the innermost region indicates the volume that is to be “mined” for ejectable material (the ejecta) – in that diagram the direction of motion is upwards.

Getting There

"*When will the space elevator become a reality?*"
"*Probably about 50 years after everyone quits laughing.*"

Arthur C. Clarke (1990) [Conw2003]

We have to look at how we are going to transport over 6 million tonnes of matter into space – together with the engineers and people. At the current transportation costs of over $200,000 per kilo **<<<CHECK THIS<<<** this is an unspeakable cost – well, not unspeakable: just say "$1.2E+15" quickly and the problem goes away (the problem of *speaking* goes away – the problem of getting the money remains). A little ingenuity can reduce this (*must* reduce this!) twelve hundred million, million dollars to something smaller.

There are several modes of transport from Earth to consider: standard rocket propulsion, sling-shots, using an intermediate way-station with a smaller gravity well (for example, the Moon), and the space elevator.

Rockets

We are used to rockets, and are very familiar with how they work. But they are expensive, both in the amount of energy required to transport the cargo, and in the weight ratios possible between the fuel and the cargo. They are also limited, because of this ratio, in their maximum attainable velocity.

$$\Delta v = v_e \ln (m_0/m_1)$$

where v is the velocity, Δv the change in velocity, v_e is the effective exhaust velocity, m_0 is the total initial mass (including propellant), and m_1 is the total final mass. This is Tsiolkovsky's Rocket Equation, and covers all forms of rocket propulsion (but is not applicable to sling-shots, gravity engines, the space elevator and other techniques).

We require Δv to be greater than 9.8 m/s to reach orbital velocity, and the higher the value of v_e we can achieve, the smaller we can allow m_0/m_1 to be.

If we can use 80% of the initial mass as propellant, and expel this with a v_e of 980 m/s then the maximum Δv is $980 \cdot \ln (100/20) =$

980 · 1.609 = 1557.25 m/s. For every 1E+6 kilo transported, though, we need 4E+6 kilo of fuel. We are estimating at least x kilo to be transported, which would mean x kilo of fuel – a nearly impossible amount.

<<<MORE HERE

Sling Shots

<<<MORE HERE

Way-Stations

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Space Elevator

Technique

Amongst the possibilities for cheap low-orbit/high-orbit transfers of matter is that of the Space Elevator. This is, effectively, a lift[62] that runs up from a point on the Earth's (Terra's) equator to a geo-stationary (geo-synchronous) satellite and beyond. The idea (for some of the designs) is to first create a geo-stationery satellite that has some substantial mass – much greater than any unit of cargo subsequently to be transferred – and drop to Earth (Terra) a (strong!) cable. At the same time a similar cable would be extended outwards, beyond the orbital point, so that the structural centre of gravity would remain in the initially-constructed satellite (to retain stability). There are other designs, covered in [Edwa2003] and [Edwa2003b]. See also [Chan2003], and for an entry in to general discussion see [Edwa2003c].

This gives a "rope that can be climbed into space", at very much cheaper energy costs than using massive explosive propulsion. The Space Elevator has also been called "the ribbon in to space", as we anticipate the shape of the rope being flat-ish, like a very thick ribbon. The "rope… into space" is often called "the ribbon", If there were power transmission up and down the ribbon we could minimise the amount of power-transformation gear that would

62 American "elevator" = British "lift"; American "lift" = British "hoist". This is the point where the obligatory quote has to be made about "two great nations divided by a common language".

have to be carried. It turns out that the carbon fibre currently being investigated is a non-conductor, so one line of research is that of beaming power by laser transmission to the pod climbing or descending the ribbon. Then we could send items up into space without having to send up with them the engines that transport them there.

Research

Constructing such a ribbon is not easy. The tensile strength would have to be great enough to (a) sustain the weight of over 90,000 km. of cable and the weight of the items being transported[63]. It seems, currently, that we have to wait till we can construct long carbon monofilaments or "bucky-tubes" that bind with molecular strength. This is a materials challenge, which we are now looking at – but with insufficient funding to get the answer soon. It seems that we could have the technology – at current rates of progress – to construct a Space Elevator within fifty years – or (with an initial expenditure of $\$1 \cdot 10^{10}$ – a very achievable sum) twenty years ([Edwa2003] p.2).

The strength required for a Space Elevator cable is about 100 GPa. The theoretical maximum for carbon nanotubes (first described in [Iiji1991]) is 300 GPa, and samples have already been constructed with strength of 63 GPa. ([Edwa2003] p.7). The strength of steel is typically only 3 GPa. (in any case, under 5 GPa.), and of Kevlar only 3.7 GPa.

The Space Elevator has to be "anchored" somewhere. The anchor point should be at, or near, the equator. This gives only a few possible countries (*e.g.* Brazil, Colombia, Congo, Ecuador, Gabon, Indonesia, Kenya, Somalia, Tanzania, Uganda, Zaire), and a lot of ocean to choose from. Edwards ([Edwa2003] and [Edwa2003b]) discusses an ocean anchor point, 1,000 miles west of the Galapagos Islands. The island nation of Nauru is only 26 miles from the

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63 Edwards [Edwa2003] suggests a range of 91,000 km. to 117,000 km. A length of 91,000 km. is adequate to reach the Asteroid Belt (which is required for this project) and Jupiter – as well as Mars and Venus. To reach Saturn requires about 117,000 km., and so on up, till we can reach Pluto at (about) 135,000 km.

equator, in the Pacific ocean, and there is one point in Peru that is even closer: these also may prove to be suitable.

Whatever anchor point is ultimately chosen does not concern us here – merely that one (or more) is chosen, and one (or more) Space Elevator is constructed. We would then be able to achieve an Earth-to-orbit cost of under $1,000/kg. This then reduces our base lifting cost (for the interstellar ship) to just $6E+12 – two orders of magnitude lower, and still a large number, but much more achievable.

Safety

There are problems of safety and disaster recovery that will have to be considered – what happens if the ribbon (rope) breaks, for example? Will there be political, and military, conflict about the anchor point? Can we – and will we – build more than one elevator? What happens when an ascending/descending pod gets stuck? Can we trust the transmission of motive power to the pods by laser (or other) radiation? Have we calculated the effect of tidal attraction upon the orientation of the ribbon?

I happen to believe that monofilaments *can* be created, and that we will solve this particular problem fairly soon (within the next fifteen years – prior to 2020), even without extra funding for space research – there are many other uses for such strong materials. We have already managed to construct extremely large molecules[64] (by polymerisation), and extremely large perfect metal crystals[65] (for turbine blades). And we are actively researching the construction of monofilaments, and other complex fullerenes.

Transportation Energy

For the engines required to transport items up and down the elevator, we have to look at drives such as the

64 Metres across – tens of metres in the case of poly-toluene.

65 Several centimetres across and immensely strong – without them many fighter jets simply would not work. The technique of building these crystals shows human ingenuity in ensuring that only one nucleus of crystallization exists for one blade. [REF????]

magnetoplasmadynamic (MPD) thrusters ([Edwa2003] p.21), being studied at Princeton and JPL, and elsewhere. Such electrically-driven drives do not require us to carry large amounts of explosive material with the cargo, to achieve propulsion.

Cost

Edwards has suggested that a Space Elevator cable could be constructed for under $\$7.5 \cdot 10^{9}$ – though later increased this to $\$1.0 \cdot 10^{10}$ over 15 years ([Edwa2003] p.43). This is a small enough sum that an individual[66] could finance it, rather than a corporation or a government. The project itself is likely to be, overall, $\$4.0 \cdot 10^{10}$ for the first elevator, and under $\$1.5 \cdot 10^{10}$ for the second and subsequent elevators ([Edwa2003b] p.11.5). Even if these estimates are too optimistic by a factor of ten, that gives us two elevators for a construction cost of under $\$5.5 \cdot 10^{11}$. The USA military expenditure is already more than that every year.

The safety of a Space Elevator is, however, very finely balanced: it "straddles a fine line between impossibility and too fragile to survive" ([Edwa2003b] p.81). We know already that space exploration is risky. The risk, however (IMHO), is necessary.

Even if these costs are an order of magnitude out, and the Space Elevator costs, say, $\$1.0 \cdot 10^{11}$ or as much as $\$5.0 \cdot 10^{11}$ that is still only a tiny fraction of the overall project cost. And without the Space Elevator – or equivalent – the overall project cost would be prohibitive.

"*The space elevator will be built about 10 years after everybody stops laughing. And they've stopped laughing.*"

Arthur C. Clarke (2003) [Conw2003]

66 If the individual were, for example, Bill Gates.

Terraforming

There are three possible ends for our travellers:

- They will all ultimately die in space. That is, the ship (or ships) have a finite lifetime, and will eventually peter out, or
- They will continue for a long time – not for ever, as that is not (in the abstract) possible – in space, themselves producing more ships and spreading to more ships, making some of mankind effectively a space-dwelling creature, or
- They will discover a suitable planet, terraform[67] that planet (or adjust their own descendents biologies to be able to use that planet), and live there.

This is not the place to discus terraforming in any detail - it is a branch of engineering yet to be explored, and about which we know next to nothing[68]. The travellers have to remember, however, that these are their only three possible ends – they have to be aware – and kept aware – of the unstable nature of their life-support systems, and of their vulnerability. A terraformed planet is – by the very nature of its size – less unstable[xviii].

67 Terraform: to modify an environment to make it more like Earth (Terra), and capable of supporting terrestrial life forms.

68 Maybe *we* do not know next to nothing on this – but *I* certainly know next to nothing on it!

Biology

"He who wants to build an apple-pie from scratch must first invent the whole universe."

Carl Sagan

Preamble

Journeys require people. People are biological mechanisms. Supporting a group of people for a long period of time raises both biological questions (How are they to be fed and sustained? How can they form a stable breeding colony? etc.), and sociological questions (How can their groupings be organized? What will make their lives worthwhile? What language will they use? How will they entertain themselves? etc.). These, too, like the hardware engineering questions, are difficult questions, and simple answers do not instantly spring forth.

If, dear reader, you are intent upon writing science fiction based on this document, here is a good place to start – for it is in the intra-personal relationships, and the individual's perception of his environment that fiction plays. I, however, am going to consider here only dry facts. And this will be under two main headings: Biology and Sociology – though some topics could be considered under either heading – and neither of these is simple.[69]

In this section we shall consider (i) how the travellers can be supported, and (ii) how they can be given medical support, and (iii) how the travellers can breed. That is, we consider what they can eat (and go on eating), how they can be kept healthy, and how many (etc.) there must be to form a stable breeding colony (and under what organization, etc.).

We also need to consider what biological stocks are to be taken on board, even though these are "useless" – for example, decorative (but non-edible) plants (roses, daffodils, pampas grasses, cacti), pet animals and birds (such as cats and budgerigars), wild birds (such as eagles and kingfishers and cuckoos), predators and scavengers

69 בראשית, ברא אלוהים, את השמיים, ואת הארץ.
Bereishit bara Elohim at ha shamaim ve at ha eretz

(such as leopards, foxes and badgers) and freshwater and seawater creatures of apparently zero utility, such as sea urchins and minnows.

Mass Proportions

What matter is needed?

[RECAST FOR 120,000 population] No matter what organization decisions are taken, if we are considering a population of 120,000 people, then we have to consider a total of 12,000,000 kg. (1.2´10^{7} kg.) of organic matter just in the people alone[70]. If we consider that there has to be at least 10,000 kg. of organic matter to support each person then this gives a total of $1.2 \cdot 10^{11}$ kg. of organic matter (a hundred and twenty million tonnes). And for larger human populations, this naturally multiplies up. For our hypothetical maximum of one million people these figures come to $1.0 \cdot 10^{8}$ kg. of people, and $1.0 \cdot 10^{12}$ kg. of organic matter.

Note that we do not have to transport the totality of this matter from Earth's gravity well – we *do* have to bring a small, breeding, sample of each species that we want – but if we can get the carbon, nitrogen, oxygen, etc. in space, from (say) the substance of an asteroid, then we can grow much of this organic matter – converting elemental and inorganic forms (which are already there) into organic forms. This is particularly important for the species of which we require a great number of instantiations – grasses, wheat, rice, barley, edible vegetables, etc. We do not have to take up enough cabbages to feed a hundred and twenty thousand people – only enough cabbages (and cabbage seed) to be able to *breed* enough cabbages to feed a hundred and twenty thousand people, and so on...

Of course, we have not yet established here what the ratio should be, from "mass of people" to "mass of other organic matter", and the previous paragraph merely assumes a ratio of 1:100. On Terra the ratio is far greater – mankind is a lot less than 1% of the living material on the planet[xix]. When we establish the correct ratio (and I think it will surprise us) we have to remember that we are trying to construct a stable, sustainable environment that is rich to live in. The consequential masses will be very large. In this document I am going to assume a ratio of 1:1000 – that is, for every 1kg of mankind there is 1,000 kg of other living matter. This gives us a base of $1.2 \cdot 10^{12}$ kg. of organic support (one thousand two hundred

70 At the rather generous figure of 100 kg. per person.

million tonnes) at the very outset, climbing potentially to $1.0{\cdot}10^{13}$ kg. (ten thousand million tonnes).

As a mental image for size, assume that biological matter has a density of about one – the density of water. This means the maximum volume is $1.0{\cdot}10^{13}$ litres or $1.0{\cdot}10^{10}$ m^3 or ten cubic kilometres. The volume of one of the smallest asteroids we have considered (*43 Ariadne*) is more than 143 thousand cubic kilometres – the organic matter would be less than one fourteen-thousandth of its volume, even at the most crowded. [The volume of *215 Kleopatra* is about 840 thousand cubic kilometres.] Allowing a whole cubic metre for each person (in reality, only Sumo wrestlers exceed this!) the volume of the crew is at most one thousandth of a cubic kilometre.

It is rather odd, is it not, that what we blithely consider as our "most important" part of the ship's contents (its crew) constitutes about the smallest proportion of its mass?

Observed Proportions

Looking at the universe, as we experience it, the various elements are in the following amounts (measured in parts per million, ppm.) in the universe as a whole, in Terra's crust, and in seawater (at 3.5% salinity).

Composition of Sol is listed as Hydrogen (H) 92.1%, Helium (He) 7.8%, Oxygen (O) 0.061%, Carbon (C) 0.030%, Nitrogen (N) 0.0084%, Neon (Ne) 0.0076%, Iron (Fe) 0.0037%, Silicon (Si) 0.0031%, Magnesium (Mg) 0.0024%, Sulphur (S) 0.0015% and all others 0.0015%.

Roughly, Terra with the other inner planets[71] and their moons[72] are (by mass) 35% iron, 30% oxygen, 15% silicon, 13% magnesium, 2.4% nickel, 1.9% sulphur – which leaves just 2.7% for everything else. [Earth (Terra) overall is (by mass) 46.6% oxygen, 27.7% silicon, 8.1% aluminium, 5.0% iron, 4.6% calcium, 2.3% sodium 1.5% potassium, 1.5% magnesium, leaving about 2.7% for

71 Mercury, Venus and Mars.

72 Luna, Phobos, Deimos.

everything else]. The Jovian (outer) planets[73], with their moons (too numerous to name!) are roughly, by mass composition, 74% hydrogen, 24% helium, 0.6% water, 0.4% methane, 0.1% ammonia, and rocks and metals about 0.3%. Within Terra's atmosphere, and life-forms, we have other proportions, which we observe as in the following table, to which we have added some observations of our technical use of the elements (in machines, furniture, clothing, and our other artefacts):

Oxygen	49.2%
Silicon	25.7%
Aluminium	7.5%
Iron	4.7%
Calcium	3.4%
Sodium	2.6%
Potassium	2.4%
Magnesium	1.9%
Hydrogen	0.9%
Titanium	0.6%
Chlorine	0.2%
Others	0.9%

Observed Proportions of Elements on Terra

These proportions (in the bio columns) are those observed in organic life-forms on Terra, with a greater emphasis being placed on land-dwelling forms than sea-dwelling – even though that is not the proportion observed in nature itself **[Ref: ???]**. Note that we have included here, in the bio. columns, all the biological materials, including the water in which the aquatic species dwell, and the atmosphere upon which all life-forms depend. In total we are assuming $1.0 \cdot 10^{11}$ kg. of living material, **??** kg. of direct

73 Jupiter, Saturn, Uranus, Neptune, Pluto.

support material (water, air and stony soil), and **??** kg. of available technological equipment and sundry matter, irrespective of the ship housing, power-supply and propulsion.

Observed Proportion of Elements in Life Forms

Oxygen	65%
Carbon	18%
Hydrogen	10%
Nitrogen	3%
Calcium	2%
Phosphorus	1.2%
Others	0.8%

Chosen Proportions

In fact, we can assume the following split, in proportions:

Usage[xx]	**Amount in %.**
Propellant (ejecta)	50
Ship Structure (structural)	44
Active Baggage (engineering)	1
Power Supply (engineering)	1
Atmosphere (biome)	1
Living Matter (biome)	1
Water (biome)	1
Raw Matter (cargo)	1

This is – at present – only a sketch plan. It is reasonable insofar as the “carrier” is far more massive than the “cargo” It is unreasonable in that the atmosphere may not be exactly equal to the power supply in mass, and so on – but the overall ratios are reasonable. For transportation costs (things we have to lift from Terra) we do not have to consider the Propellant and we do not have to consider the Ship Structure, as both of these will be mined “in space” (coming from the body of the asteroid or asteroids that we modify to make the ship). We may be able to manufacture some of the atmosphere from naturally occurring space-rock – but in my calculations here I do not assume that.

On the ship, therefore, we are likely to have the following overall balance:

Usage	Proportion %
Ejecta	50
Structure	44
Engineering	3
Biome	2
Cargo	1

This gives us rough mass estimates [SCALE UP by x20](for 100,000 ~~5000~~ initial crew) of:

Number of humans	100,000 ~~5000~~ $1 \cdot 10^5$
Average mass per human	100 kg. $1 \cdot 10^2$ kg.
Total human mass	$1 \cdot 10^7$ kg.
Biomass support per human	$1 \cdot 10^5$ kg.
Total biomass support	$1 \cdot 10^{12}$ kg.
Allowing for error, loss, expansion etc.	$4 \cdot 10^{12}$ kg.
Total Biomass, engineering and cargo	**$4 \cdot 10^{12}$ kg.**

This $4 \cdot 10^{12}$ kg. (four million million tonnes) is the minimum amount that we will have to transport into space to furnish the ship. Since, by our previous "broad-brush" estimates this is only 6% of the total Ship mass, the ship overall must be at least $1.0 \cdot 10^{14}$ kg. in initial mass – and when choosing an asteroid (or asteroids) to convert we can use this as part of our selection criteria.

Ejecta and Structure

The Substances for the ejecta and the structure are only important insofar as they must not be dangerous to the inhabitants – poisonous or radioactive. For the ejecta, it must be "sufficiently massive" (which, for our model, we assume is just under 50% of the initial mass of the structure/asteroid). For this and for the Structural component, we are dependent upon the substances(s) of which the original asteroid(s) is/are composed.

We do not have to transport this matter into space from Terra – we should use matter that is already there. If we are hollowing an asteroid, for example, we use the matter of the asteroid itself. The ejecta and structure are by far the largest proportion of the matter of the ship – at least 94% of it.

Engineering

For the Engineering, however, we have – and must make – a choice. The number of elements for the engineering is likely to be the largest – arguably we should have “something of everything”. For example, the engineering will require germanium, gallium, tungsten and uranium – which are not required by the raw biology of the ship.

Some of the engineering will be lifted from Terra, but we should also look to manufacturing some of it in Space from existing Space material. The Engineering is likely to constitute 3% of the total mass of the ship – which is a very large amount. To cut down on its expense we should manufacture as much as possible of it *in situ*.

Cargo

For the cargo – what is carried in addition to the machines and the people – again we can make a choice. But this choice is governed by “what we want to carry with us”. For example, we may choose to take a few Stradivarius violins, but no painting by Rembrandt. – or the reverse – but the substances of which these works of art are composed are irrelevant to our considerations here. For the proportions of the elements we have to carry on board, the cargo will not be considered.

The cargo can *not* be manufactured in Space – it is what we are carrying from Terra, and can come only from Terra. Although it is possibly as much as 1% of the total mass of the ship, we have to accept the cost of its initial launch into Space.

Biome

The biome must – largely – come from Terra, having been transported into Space. Some *small* proportion of it can be grown in Space – but only if we can find the necessary carbon, nitrogen, oxygen, hydrogen (etc.) in sufficient quantities, and able to be converted into biologically useful forms. On the whole, we have to be prepared to accept the cost of transporting up from Terra this 2% of the total ship mass. In my calculations I have assumed, however, that we will be able to "grow" half of it in Space, and that we have to transport only half of it from Terra.

For the biome, there are natural laws that we cannot but observe: if there is insufficient oxygen (for example) there can be no life. Hence the proportions in the biome must approximate those on Terra, and in the life-forms on Terra. In our calculations we assume that living matter constitutes just 10% of the biome, and that the rest is in the proportions of (raw) Terra. <<FIGURES BELOW ARE WRONG!!>>

Element	Terra %	Life %	Ship %
Oxygen	49.2	65	50.78
Silicon	25.7	0	23.13
Aluminium	7.5	0	6.75
Iron	4.7	0	4.23
Calcium	3.4	2	3.26
Sodium	2.6	0.1	2.35
Potassium	2.4	0	2.16
Magnesium	1.9	0	1.71
Hydrogen	0.9	10	1.81
Other	0.9	0.6	0.87
Titanium	0.6	0	0.54
Chlorine	0.2	0.1	0.19
Phosphorus	0	1.2	0.12
Nitrogen	0	3	0.3
Carbon	0	18	1.8

These proportions will have to be thought through again at the time of construction (or nearer to the time of construction), as there are a number of factors that have not been taken into account here. For example, certain elements are limits to the number of human beings that can be supported, whilst not being limits to other life-forms. The proportion of living creatures to supporting biomass may not be 1:9 or 1:100, but something else. (We are – almost arbitrarily – assuming 1:1000 in this document). We may have to carry more "spare" of some elements (*e.g.* oxygen) than others because of their importance, or rarity in space.

[>>>HOW can we get a grip on the human/lifeform/inanimate mass ratio for a stable biosystem?<<<]

If we assume a maximum comfortable human population of 10,000 [RECAST TO MAX 1,000,000 – a hundred times more <<<] with a total of 1E+9 kg for each of the categories of (1) organic matter (people, animals, soil, plants), (2) water, (3) air, (4) engineering and (5) power supply. Then we have the following possible weights of the extractable elements to be taken on board. Note that this table does *not* consider the cargo of works of art, books, cultural artefacts or whatever else is taken on board that is not necessary for the physical support of the crew, but will contribute to their happiness. We assume that this cargo is another $1.0 \cdot 10^9$ kg.

[>>>RECAST ABOVE FOR BASE POPULATION OF 120,000, MAX POPULATION OF 1,000,000<<<]

Eating

Not all our travellers are vegetarians. So we have to have some sort of meat with us. Even if you, dear reader, happen to be vegetarian, remember that meat-eating gives energy in a very compact way – it is an efficient food **[Ref: ???],** by one measure of efficiency[74]. So as well as growing crops, the travellers have to be able to support livestock. There has to be enough livestock to form stable breeding groups, and much the same consideration has to be given to numbers of these as to the numbers of people (considered in a later section).

So this section is divided into crops and livestock. Since the

74 If we consider only the land-use side of efficiency, then soya is more efficient – but we are not going to condemn all our descendants to just that.

livestock depends upon the crops, we cannot decide finally on the *necessary* crops until we have considered the livestock we want. We can, though, consider some of the *unnecessary* crops (the decorative and the curious and the inedible)

Sustaining a stable biome is not just about eating – it is about having a sufficiently large and diverse stock of animals and plants (*etc.*) to be able to sustain a human colony for generations, without boredom, with variety, and to be able (perhaps) to stock a new planet, should we meet one. We should be carrying, too, as wide a genetic diversity as we can, with one aim of creating new species – a possibility for the future (but not now).

Livestock

Edible Livestock

We can – and do – eat animals, birds and fish. Some cultures eat insects too. Animals: cattle, pigs, sheep, goats, camels, deer. Birds: chicken, ducks, turkeys, geese, game birds. Fish: freshwater and saltwater: salmon, cod, prawns, plaice, crabs, sharks, eels etc. etc. [Was there an old division of Terra's creatures into those that walk, those that swim and those that fly?]

Non-Edible Livestock

This includes pets and predators, and any other species that we think we should take with us to a new environment. Some will be easy to justify, as being useful (dogs, cats) or of little economic impact (budgerigars, parrots). Some will be difficult to justify (rats, mice, poisonous snakes). We cannot, I think, take everything. That is, we cannot consider taking a blue whale on board ship, though dolphins might – just – make it. We are unlikely to be able to justify the condor or the golden eagle – but the vulture may well be included, and may be a good means of keeping parts of the farming areas clean.

We have to be careful not to be over squeamish in our thinking. Quite nasty animals have good uses, and may have to be included (*e.g.* civet for scent, rats for scavenging clean, toads for slug control, sharks for meat). Quite surprising animals are mandatory for strange reasons – for example some species of baobab are pollinated by bats, not insects – so if we want to grow baobabs (and not have to pollinate them forever by hand) then we would have to have the right bats too. [??? Is there not an edible fruit that uses bat pollination??? FIND OUT]

Crops

Edible Crops

There are four sorts of land crops that mankind eats: (i) roots, (ii) grasses, (iii) vegetable bulk, and (iv) the seeds and seed-containers of trees and shrubs. These include (for example) (i) carrots, turnips, etc., (ii) wheat, maize, barley, rice etc. (iii) cabbage, lettuce, leeks, (iv) beans, peas, tomatoes, apples, cocoanuts, walnuts, chocolate, etc. Some crops provide substance (*e.g.* potatoes and rice), some provide valuable nutrients (*e.g.* cabbage and carrots), some provide flavour (*e.g.* garlic, onions, rosemary, chilli) and some provide, simply, additional variety to their nutrient efficacy (*e.g.* guava, kiwi, pistachio nuts). There is some use of seaweed, though very little compared to the land crops.

Some plants are required by the livestock – man does not eat grass, for example, but cows and sheep certainly do – and grass would be needed for them.

Non-Edible Crops

These include decorative plants (*e.g.* roses, lilies), useful plants (*e.g.* trees for the production of wood and paper), and plants that we consider we should take – perhaps for genetic variety, and perhaps because we want a rich environment throughout.

There are dual-use plants that can be used both for food and for other purposes (*e.g.* the walnut, which provides both fruit (the nut) and a hard decorative wood).

Health

Medicine

Breeding

If we consider a population in which we have, during any 5-year period, 8100 male birth-survivors (*i.e.* males who reach their first birthday), and 7700 female survivors, then by applying roughly the mortality statistics of the UK in 2001, we get the following population pattern emerging:

Ages	**Males**	**Females**	**Total**
0-4	8100	7700	15800
5-9	8000	7600	15600
10-14	7900	7500	15400
15-19	7800	7400	15200
20-24	7700	7300	15000
30-34	7600	7200	14800
35-39	7500	7100	14600
40-44	7400	7000	14400
45-49	7300	6900	14200
50-54	7100	6800	13900
55-59	6800	6600	13400
60-64	6400	6300	12700
65-69	5800	5900	11700
70-74	4900	5300	10200
75-79	3600	4400	8000
80-84	2000	3200	5200
85-89	600	1800	2400
90+	0	500	500
Totals	**106500**	**106500**	**213000**

Of course, these are only approximate figures – we cannot know now the true mortality statistics for a space population. Similarly, there will be tragic accidents (wiping out more people), and happy accidents of birth (giving burst of population increase). In the table above there are a total of 14500 females between the ages of 15 and 40. If we consider this to be the "breeding population, then we have 7900/14500 (0.55) surviving births per breeding female in a five-year period. This comes to 2.75 births per breeding female over her breeding lifetime.

Year	**Age of mother at birth**							
	All ages	Under 20	20-24	25-29	30-34	35-39	40-44	45 +
1995	60.5	28.7	76.5	108.0	87.3	36.6	6.5	0.3
2001	54.8	28.0	69.3	91.9	88.2	41.6	8.4	0.5
Avge.	57.65	28.35	72.9	99.95	87.75	39.1	7.45	0.40

Calculating forward, births at these rates are insufficient to sustain the population – the rates actually need to be (in gross) about 7% higher, give (about) 61 births per thousand women per year.

The above diagram shows how population could be made to (statically) stabilise, based on the number of births per thousand being related to the total population. This diagram uses a multiplication factor upon the base birth-rates shown above of (1+(10000-N)/50000), where N is the total population. For the starting figures quoted this gives a final population of (total) 6336 people.

If we look at imposing a random element up the death (and birth) rates – as would occur in reality – the curves are not quite as smooth, and do not grow as fast. Thus we would get (for births), starting from the same base figures, but with more flexibility (variability):

And for the total population:

This presupposes good control over birth-rates – which (given the highly technological nature of this proposed future society) seems quite reasonable. The exact birth-rates control the final population size – with the figures used in this second pair of examples the population dynamically stabilises at just over 11,000 – nearly twice as big as the earlier example.

In reality, disasters are likely to be much more extreme, and we should expect occasional large population dips, as in:

The above show population dips showing as much as a 20% loss of population in one event. The births to maintain this population, though, as much less varied:

If we allow for even larger disasters which may touch as much as 80% of the population in one hit, then we could see figures like:

In the above example, there are four major disasters – which eventually wipe out the whole population – even though some recovery takes place after each disaster. The birth numbers, in this particular (manufactured) example, are:

Or, if this is expressed as "live births per 100 population", this requires:

Despite the disasters, this is a sustainable (though rather high) birth-rate. On Terra in 2003 the birth rates per thousand population varied from over 49.9 per thousand (in Niger) down to 8.02 per thousand (Bulgaria). If, in our model, we (a) limit the birth-rate to be as "standard" about 21 per thousand (which was the estimated World-average for 2001), and (b) allow it to reach 47.5 per thousand *in extremis,* but (c) normally prefer the rate to be at the "stability" level of 2.1 live births per breeding woman [or slightly below – this depends upon overall mortality rates], then we might see patterns like those represented in the following diagrams, for overall population (including occasional large disasters). Note that the number of live births per woman, in the world, ranges from 1.15 (Spain) up to 6.81 (Mali). To sustain the population we need at least 2.03 live births per breeding woman, assuming that 98.7% of the women breed. There are more details on this in the section on Costs, below (page ??).

Population Density

The United Kingdom has fewer than 250 people per square kilometre. On Terra our population densities per country vary from nearly 2.1E5/km^2 for Macau down to only 2/km^2 for Namibia. Anything from 1/km^2 to 1E3/km^2 (the current population of Maldives) is perfectly acceptable. At a population density of 1E3/km^2 each individual person (man, woman and child) has 1E3m^2 of their own space.

If we are considering an initial crew of 120,000 (1.2E+5) and a maximum crew of two million (2E+6) then at a density of 200/km^2 we have to be able to have a habitable area of from 6E8 to 1E10 m2 or 600 km^2 to 20,000 km^2. On a ship of interior dimensions of 39 by 13 by 13 (about the size of 433 Eros) we have over 65 thousand km^2.

(1.2E5/200)·1E6 and (2E6/200)·1E6 m^2 = 0.6E3·1E6 and (1E4·1E6) = 6E8 m^2 and 1E10 m^2 [1993 Terra: habitable is split as 13.1% Arable, 4.7% crops, 26% pasture, 32% forest and woodland, 1.5% urban, 30% other] [Population 6.7E9 July 2008, area 510 (all)]

Terra's population density may not be a completely relevant to measuring the ship, though. On Earth we have deserts and oceans and mountain ranges which have strong effects upon the atmosphere and the climate, but are not themselves habitable or direct producers of foodstuffs or minerals for mankind. The surface area of Terra is 6.3E7 km^2 (just the habitable land) or 1.489E8 km^2 (all of the land) or 5.1E8 km^2 (the whole surface). With a world population of 6.7E9 (now, in 2008, an underestimate), that gives a total population density of [6.3e7/6.7e9=0.94e-2 km^2 per person, or 6.7e9/6.3e7 people/km^2 = about 1.06 people/km^2] 118 per km^2 (habitable land) or [1.48e8/6.7e9 km^2/person-0.22e-1=2.2e-3km2/person, or 454 eh??? Try again… 1.489e8/6.7e9 km2/person = 0.22e-1 = 2.2e-2 km^2/person (better!) = about 45 people/km^2] 50.5 per km^2 (all land) or [5.1e8/6.7e9 km2/person =7.6e-2 km2/person or 13.2 people/km2] 14.7 per km^2 (the whole planet). If these densities are applied to a single shell with the dimensions of 433 Eros (area 6.5E4 km^2) then the largest populations would be 2.38E5 (habitable) or [6.5E4·14.7] 9.5E5 (all).

What gives this factor of 4:1 in this statement? How have we decided what proportion of the total inside surface is habitable? Partly because of pseudo-gravity, partly because of background engineering. Because of both its direction and strength, at most half of the inside surface of a rotating sphere is habitable. Because of engineering half of what remains has to be counted out of habitability, leaving us only a quarter of the original area. Only about one eighth of the Earth's total surface can be counted as habitable.

Radius km	Area km²	Popln. at 1/km²	Popln. at 14/km²	Popln. at 45/km²	Popln. at 118/km²
1	1.26E+01	1.26E+01	1.76E+02	5.65E+02	1.48E+03
2	1.01E+02	1.01E+02	1.41E+03	4.52E+03	1.19E+04
3	3.39E+02	3.39E+02	4.75E+03	1.53E+04	4.00E+04
4	8.04E+02	8.04E+02	1.13E+04	3.62E+04	9.49E+04
5	1.57E+03	1.57E+03	2.20E+04	7.07E+04	1.85E+05
6	2.71E+03	2.71E+03	3.80E+04	1.22E+05	3.20E+05
7	4.31E+03	4.31E+03	6.03E+04	1.94E+05	5.09E+05
8	6.43E+03	6.43E+03	9.01E+04	2.90E+05	7.59E+05
9	9.16E+03	9.16E+03	1.28E+05	4.12E+05	1.08E+06
10	1.26E+04	1.26E+04	1.76E+05	5.65E+05	1.48E+06
15	4.24E+04	4.24E+04	5.94E+05	1.91E+06	5.00E+06
20	1.01E+05	1.01E+05	1.41E+06	4.52E+06	1.19E+07
25	1.96E+05	1.96E+05	2.75E+06	8.84E+06	2.32E+07
30	3.39E+05	3.39E+05	4.75E+06	1.53E+07	4.00E+07
35	5.39E+05	5.39E+05	7.54E+06	2.42E+07	6.36E+07
40	8.04E+05	8.04E+05	1.13E+07	3.62E+07	9.49E+07
45	1.15E+06	1.15E+06	1.60E+07	5.15E+07	1.35E+08
50	1.57E+06	1.57E+06	2.20E+07	7.07E+07	1.85E+08
55	2.09E+06	2.09E+06	2.93E+07	9.41E+07	2.47E+08
60	2.71E+06	2.71E+06	3.80E+07	1.22E+08	3.20E+08
65	3.45E+06	3.45E+06	4.83E+07	1.55E+08	4.07E+08
70	4.31E+06	4.31E+06	6.03E+07	1.94E+08	5.09E+08
75	5.30E+06	5.30E+06	7.42E+07	2.39E+08	6.26E+08
80	6.43E+06	6.43E+06	9.01E+07	2.90E+08	7.59E+08
85	7.72E+06	7.72E+06	1.08E+08	3.47E+08	9.11E+08
90	9.16E+06	9.16E+06	1.28E+08	4.12E+08	1.08E+09
95	1.08E+07	1.08E+07	1.51E+08	4.85E+08	1.27E+09

100	1.26E+07	1.26E+07	1.76E+08	5.65E+08	1.48E+09

There are engineering decisions to be made about how the inside of the ship will be hollowed. It may be as a single large cavity, which gives the smallest surface area for the volume. It may be as a series of nested shells, each of which adds to the area contained within the given volume. It may be as a series of cells, which may include a large central void, but need not. This gives even more surface area. Each of these techniques offers its own problems of power distribution and varying pseudo-gravity strengths and aesthetics – but, as we will see [REF], the design process cannot be a short one, and the design phase cannot be completed quickly.

On the ship we have to allow for engineering spaces – structural support, transportation, primary energy supply, atmospheric maintenance that are naturally provided on Terra by the planet itself, its orbit in space, Sol and the rest of Terra's biome. We can interfere – and we do interfere, with poor consequences – but for the largest part we do not have conscious choice in these matters. On the ship, however, we will have conscious choice and, more than that, primary responsibility for these.

>>>MORE HERE<

Culture

Lady Bracknell: *A Handbag?*

Oscar Wilde [Wild1895]

Prior Art

What can the travellers understand (or be expected to understand) of prior Terran art? There will be illustrations, which will be (perhaps) viewed as fascinating, nostalgic, curious, puzzling, totally baffling, bizarre curiosities, unvalued trifles, rubbish, items to be ignored, ancient treasures (their state changing as time goes on). There will be works of music (which can be expected to last for several hundred years – and which can be in many forms). There will be poems – which (like theatre) can last only as long as enough of the language lasts, *and* enough of the referenced culture lasts. For example, poems about falling in love will last a long time – mankind will continue to fall in love on the ship: poems about Waterloo Station [Davi1967], or positing that "*April is the cruellest month*" will not ("*...A crowd flowed over London Bridge, so many / I had not thought death had undone so many. ...*" [Elio1922][xxi]).

Existing dramatic works, whether for theatre, TV, film or impromptu performance, are of use only as long as enough of the language and the historic knowledge last. The words "A handbag?" may well have reminded you[75] of the play *The Importance of Being Earnest* by Oscar Wilde [Wild1895]. But if they didn't, you could have looked them up. Perhaps you have seen and remember notable performances of that play. Perhaps you like that play, perhaps you don't – but you are certainly able to understand its societal references, even though you are not part of that defunct society. Our 21st century appreciation of Shakespeare's works is slightly more limited by our distance from the social norms of his time, by our familiarity with the powerful language which was, to his first listeners, completely new, and by our distance from and ignorance of the political and religious movements of his time – contemporary and common knowledge then, but available to us (if

75 I am assuming that you are reading this in the 21st century.

at all) only by long and careful study.

The interpretation of the visual arts is also locked in to the culture of the time – Classical Greek statues, for example, were admired in their time, and deemed to be the best forms of sculpture[xxii], but these were overtaken by Medieval styles, by Renaissance shapes (in which their artists thought they were referring back to Classical Greece), by more fluid forms, further removed from the exact representation of the outside world, through to abstract forms, some of which are distorted, modified representations of the “real world” (*e.g.* Bacon[76], Giacometti[77]), and some which are only very distantly related to “real world” representations, or not related at all (*e.g.* Henry Moore[78]).

One view is that no works of art, other than music, should be taken on board at all. Any physical artwork taken on board is lost to Terra for ever. Another is that a very small amount should be taken – literature, music, a very few paintings, a large number of *copies* of paintings (on CD or whatever digital reduction is then used), but no (or very little) sculpture, no (or very few) artefacts – though this might be interpreted to mean desk decorations, Newton’s Cradles, decorated pen-holders, netsuke – all of different aesthetic levels And yet another view is that on board should be at least as much art as there would be in any Terran community of two hundred thousand people – twice as much as there is in the Exeter Museum, with the cathedral and private collections included.

No deep discussion on Art can be simple. See http://en.wikipedia.org/wiki/Art for an excellent starting point. Your favourites may not be my favourites. And any art or art form that we do not include on the ship is potentially lost to the first

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76 Francis Bacon, 1909-1992, painter. “Champagne to our real friends, and real pain to our sham friends.” See http://en.wikipedia.org/wiki/Francis_Bacon_(painter)

77 Alberto Giacometti, 1901-1966, sculptor, painter, draftsman, printmaker. Sculptures often thin, etiolated, fragile, elongated. See http://en.wikipedia.org/wiki/Giacometti

78 A Henry Moore might be a lovely object – but it’s also very likely to be heavy! Sir Henry Spencer Moore OM CH FBA, 1898-1986, sculptor. See http://en.wikipedia.org/wiki/Henry_Moore

crew and their descendants for ever. Indian symbolic sculpture, West African wood-carving, Arabic calligraphy, Australian sand-painting, the art of designing and making stained-glass windows, Byzantine mosaic art and marquetry are examples of arts that require skill to perform and tuition to learn: whether we will include practitioners of these (and many, many other) arts in our initial crew is an important question for the way and shape in which the culture on board the ship will continue. And whether we include examples of these (and other) art forms in the initial ship's loading is part of that question.

Of the various arts, Literature (including Theatre, but only in its written form) and Music (also in its written form) are the easiest to transmit in bulk, and we can ensure that both of these are provided in bulk. For dance there is no really good notation, and it is best transmitted using dancers – hence in one respect it is one of the most expensive art forms to transmit. The figurative arts (drawing, sculpture, painting, calligraphy, etc.) are intermediate – some art works are small and light, but others are large and heavy.

Any example for an art that is not taken on board will have been lost, for the travellers. Here on Terra we can move between cultures, and be inspired by examples form the past, and produce new syntheses of influences that have not previously met. On the ship we should avoid making a static artistic environment, but one in which old art can continue to be appreciated, possibly in new ways. And we should have a situation in which new art, freshly inspired on the ship, can be created.

New Art

That is considering specific, existing works in these arts. But the arts themselves – music, poetry, painting, sculpture, and so on – can certainly be practised onboard, and *will* be practised onboard.

Literature

Literature will eventually be there, no matter what we decide to send – all recent civilizations have had literature, and it is neither possible nor desirable to get rid of it. The meaning of the word "literature" has to be extended to cover the memorised poems, and the mnemonic recitations that people carry with them and pass on without the use of paper[79]. As the ship continues its journey more literature will be produced onboard – perhaps (depending on ease of communications) some of this will be signalled back to Terra for our examination and enjoyment, and perhaps more new literature will be transmitted from Terra to the ship.

But these transmissions may not be made, or may not be made for long. As well as Art we have to consider Security, Psychology, and the madness of military thinking – see the sections in this document on those topics (page Error: Reference source not found and page Error: Reference source not found).

Dance

Dance is one of the easiest arts to transport – all it needs is people. And practice. It cannot be notated and encapsulated. In that sense it is one of the most expensive art forms to transport.

The gravitational environment may differ from one part of the ship to another. At any one point on the ship the pseudo-gravity should always be the same – but possibly different from the pseudo-gravity at another point on the ship. Locations closest to the axis have the smallest gravity: locations furthest from the axis have the largest pseudo-gravity. Dance depends on its gravitational environment, so this brings a new variable in to the practice and

79 Cultures that rely upon oral/aural transmission can keep their poems and histories and genealogies alive and accurate for thousands of years: *pre*-literate is not the same as *il*-literate.

performance of dance – but not an impossible one to take account of.

Music

Music is (it seems) easy to transport, but musical instruments are another matter. Musical instruments can be manufactured onboard. And song – the first form of music – requires only what dance requires: our own bodies.

There are a huge number of musical styles: Plainchant, Chinese song, Tabla, Gamelan, Rock'n'Roll, Blues, Country and Western, Baroque, Classical, Evangelical hymns, Sitar… The number of actual (and possible) different musical instruments is also long. Just as more literature will be constructed on the ship, so will be more music. And more, new musical instruments will be invented too.

The initial pool of instrumentalists will be quite large: if only 1% of the population plays a musical instrument (in reality a big under-estimate), then in our initial population of 120,000 we will have 1,200 instrumentalist. There will be selection of our initial crew which will make them a little unlike a standard statistical sample of people taken from Terra, but it is not difficult to ensure that at least 25% of them have some skill on some musical instrument. In the Victorian period more then 50% of the population played the piano – more or less well. In the late 1960s it seemed that nearly every teenage boy played the guitar, and there are several towns in the USA where 25% of the population play the guitar alone, not counting other instruments. So quite realistically we can consider that in our initial 120,000 we will have at least 25,000 musicians. I suggest the spread of skills we might expect (measured against the Graded exams of the Royal Schools of Music in the UK) would be something like:

Grade	**Number/ year**	**Total in populatio n**	**% of populatio n**
1	425	6,000	5%
2-4	800	9,600	8%
5-7	340	7,140	6%
8-8*	60	2,500	2%

Professional	10	260	0.25%
Total	**25,500**	**25,500**	**21.25%**

Graphic Arts

Drawing and Printmaking require a surface to receive the image. This can be paper (what we now usually use), but it can also be surfaces of wood and stone and papyrus and leaf and cloth – and of many other substances. Each drawing or print uses up some of this finite resource (just as it does on Terra), and we have to recognise that each work of art has a finite life – the paper will decay, it will be necessary to use the stone again, the wood will rot away. This is true here on Terra too – but we are now used to extremely long timescales, and no longer have to re-use precious vellums or parchments as palimpsests. On the ship the timescales will be shorter, and the artworks may have to be recycled faster than on Terra.

The observations that were made for the graphic arts hold for painting too, with the added expense and difficulty of manufacturing and sustaining canvas. And similarly for Tapestry, making Stained Glass, Woodcarving – and all the other arts, “big” and “small”.

The “big” arts are those that have academic and social cachet: the “small” arts are those that don’t. But beware: an art moves from one category to the other, and different cultures categorise particular arts differently – in which category is woodcarving? Cake decoration? Ice carving? Wall painting? Ceremonial drumming? IMHO *all* arts are “big” arts, no matter how trivial or irrelevant they may seem to us.

Architecture

Buildings will still be made. The large caverns opened by the excavating, to get the stuff to eject, will not be the cosy, protected environments in which we enjoy living our daily lives. We will need buildings for various functions, and we cannot now know all of those – there will be new functions arising for which, perhaps, we do not now even have a simple name. The kinds of buildings we now can predict are homes (places to eat and sleep), libraries (places to store information, and to study that information), places of worship (which will inevitably be necessary), theatres and places for public discussion, and galleries (places to display art which needs protection from internal atmospheric disturbances and from noise).

If we are constructing buildings, we will be looking at the buildings – so the buildings should be made to please the eye and excite the mind and reinforce the mood of the society. Buildings, like everything else, have a finite life and have at times to be reconstructed, repaired, torn down and completely rebuilt. Thinking about the placement and form of buildings *and their surroundings* is Architecture.

The surroundings too are part of the Architecture. There will have to be parks and public open spaces as well as enclosed areas: the appearance and layout of these strongly set the environment.

Theatre

Theatre is dangerous. It allows people to come together and explore emotional and intellectual problems, and to use both words and actions in their expression. It is dangerous because it allows people to come together. It is dangerous because you cannot easily tell at the start just what is being spoken about – comedy can be satire, tragedy can be political criticism, a play [or book] about (say) a group of brothers and sisters in a mythical country[80] may be evangelical religion.

And though it is dangerous, because we value freedom it is essential.

Artists

Artists are just people. Arts are, amongst other things, skills that are passed on. The more people we have, the wider range of arts that can be practiced. Some of those skills merge in to engineering skills – architecture and bookbinding, for example, are each both practical and aesthetic. A list of some of the arts we want onboard is below. This list is far too short. For every art, we need at least one expert who can pass on the skills of that art. This has to be noted in setting the ship's initial population.

80 *The Lion, the Witch and the Wardrobe.* C. S. Lewis, for example.

Acrobatics	Acting	Architecture	Bookbinding
Cake decoration	Calligraphy	Carving	Ceramics
Choreography	Cinema	Clothing design	Conjuring
Cookery	Dance	Drawing	Engraving
Entertainment	Furniture design	Garden design	Graffiti
Illustration	Jewellery	Literature	Makeup
Marquetry	Modelling	Music	Needlework
Painting	Parquetry	Perfumery	Photography
Poetry	Pottery	Print Layout	Printmaking
Public speaking	Ritual drumming	Sculpture	Shoe design
Singing	Tapestry	Tattoo	Television
Typography	Woodcarving		

Security & Military Action

Evading Conflict

There are two sorts of stupid destruction we mist avoid – internal dissent, and external attack both *upon* and *from* the ship. This section does *not* consider any attacks upon the ship from "little green men" – *i.e.* other external non-human intelligent life forms.

As a side comment, I think we can completely ignore the "little green men" in all our considerations, not just those of security. If non-Terran intelligent life forms exist they are extremely[81] unlikely to contact, or even detect, the ship.

External Attack Upon

External attack upon the ship may seem unlikely – but consider mankind. Our unkindness and our brutality is recorded by history again and again[xxiii].

Before Launch

During the initial building of the ship there will be continual traffic between it and Terra, for the transfer of both people and materials. Any one of these transfers might contain something for destruction. Keeping nuclear weapons away from the ship is not impossible – not trivial, but not impossible. Keeping away from the ship bacterial weapons (sources of infection) is *much* more difficult.

In setting up a reasonable degree of security – and remember, no security is ever perfect – we must avoid making the ship itself a military area, as that will, in itself, increase the other influences towards internal (subsequent) conflict.

Two of the defences of the ship are its distance, and its positive desirability. Firstly, its distance from Terra is never less than 1.8E7 miles (1.5E11 metres, 2 AU), so getting there is expensive and lengthy. Secondly, we are positing that this project is a *world*-based project, supported by or positively viewed by the great majority of mankind, its active cultures and powerful sub-groups. I am not

81 And I mean *extremely*!

saying that there will be no people or groups wanting to cause harm, but that the number and membership of these groups will be small.

It would be possible to have an initial Ship Defence Force, with the understanding that some appropriate period after launch this force would be dissolved, or merged in to the Ship Police Force. By "understanding" here I mean that the Defence Force *must* be dissolved, as there is a strong requirement to not have conflict onboard.

After Launch

If our previous actions have worked, and the ship has not been destroyed before it sets out, we still have to consider what follows.

Having built the ship it would be (presumably) considered a precious product for a while. But after a while there may well be (Terra has supported infinite madness in the past) a wish to destroy it by some military entity. *"Do what I say or the ship will be destroyed"*, *"I have already launched the guided nuclear missiles – obey me!" "Oh stuff it! What a waste of human resources – get rid of it!" "The poor travellers, how sad they must feel, how cruel it is to allow them to continue suffering century after century – it would be kinder to destroy them all now."* And even *"There are already on board the ship – and, no, I won't tell you where – several hydrogen bombs, each of which I can trigger from Earth."*

We cannot hide the position of the ship whilst it is being built. We cannot hide the initial path of the ship when it sets out. We cannot hide the ship at all for a very great distance in its travels. So, to start with, Terra will know where the ship is.

There will come a point on its journey, though, when transmission between the ship and Terra is impossible, and a point when *direct* detection of the ship from Terra is impossible. At that point we have to consider whether, for security, the ship should carry on the same trajectory, or swerve off (perhaps several times, with many years of no acceleration – no jettisoning of ejecta – to make its location and path *indirectly* detectable. This is to avoid destruction from or interference from Terra – and also to mark finally the travellers' real separation. This is the right time to wind down –

and dissolve – the Ship Defence Force. It is no longer needed for protection from our Earth-bound aggression.

At this point of separation there is no more signalling back "home", and there is no more reception of knowledge of the state of Terra. There is no more exchange of art, exchange of history, exchange of scientific knowledge and invention between the two communities – they are truly separate.

Internal Conflict

Internal dissent – the fighting of groups on board the ship – is a harder problem to avoid or minimise. There have been sub-cultures on Terra for whom fighting is suppressed by the very culture [REFS and names of cultures] but these are, alas, all non-technical sub-cultures. Even if we could start the travellers off with the most peaceable internal relations (and we should certainly try), internal conflicts will inevitably arise. Conflicts are of many sorts: language-group against language-group, religion against religion, regional conflicts over the use of and access to particular resources, power conflicts as to who should control what and which levels of society and social organizations and how particular things should be done.

There has to be some means (initially) of resolving conflicts peacefully. But more important, we need to lay down a social habit – a strong one which will survive over generations – which abhors conflict: it's no good if the first generation lives in peace only for the following generation to destroy everything in squabbling. We have spent much effort on Terra seeking peace, but we have never succeeded in retaining it for a very long time. During the whole of my life, which started externally in 1945 – and it is now [at the time of writing this paragraph] 2007, there has *always* been a war taking place somewhere, as well as numerous conflicts classified below the level of war.

An atom bomb / hydrogen bomb on Terra is an abomination – but we have lots of them. Setting one or two of these off does not have an immediate disastrous effect upon the whole of mankind[82]. An

82 Though it *might* do if exploded over Yellowstone, because of the (possible) vast volcanic consequences [Gaud2007]. This would not just be

atom bomb on the ship, though, would be a total disaster, probably annihilating all life onboard. So don't put any atom bombs on board – that's easy! Well, no, it's not: we *might* be able to ensure that no nuclear weapons have been placed on the ship, but we *will* be putting plenty of atomic material onboard, for power generation (see Power Generation, Error: Reference source not found above). So there will be the facilities, inevitably, on the ship for making atomic weapons. Now you know and I know that actually making one would be stupid: but a hundred generations hence, can we be certain that the travellers will remember this? And can we be certain that no genius or lunatic will appear onboard? No we can not – indeed, we can be certain that a genius or lunatic *will* appear onboard.

In any case, a police force will be required. There will always be, in any group of humans, minor misdemeanours, and minor personal conflicts which will require resolution. There will also be rules (laws) regulating necessary aspects of behaviour, and these have to be enforced.

External Attack From

The ship has two things with which it could damage Terra: from its distant position, which would be difficult to attach quickly, it could launch missiles; and its ejecta, as it moves off, could cause problems by striking Terra. No-one *sane* would ever want to do harm with these things – but is any military action truly sane? Is mankind truly sane?

Choosing the initial path of the ship, to prevent its ejecta damaging Terra is not difficult – tedious, but not difficult. Once the ship is beyond 20 AU all restrictions can be lifted. It is probably the case that even with the ship at 3 AU, which is its likely place of construction, its ejecta would not harm the surface of Terra – I leave it to others to make that analysis.

Because of the distance of the ship from Terra, any missiles launched from it would be visible – and hence interceptable – for a

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pyroclastic flow, such as demolished Pompeii, but pyroclastic inundation, affecting a whole continent, and having climate effects which would be extremely injurious to life on the whole planet. [BBCa2000] [BBCb2000].

long time. This is probably not a worry.

Just as biological weapons could be used upon the ship, biological weapons could be sent from the ship to Terra. Consider placing triggerable sources of infection upon the last few trips back from the ship to Terra. These have no effect upon the ship – but could have a nasty effect for life on Terra.

Psychology

Sociology

In this section we make a first of consideration how the travellers interact, how they will use their time, how they can be organised to form a stable social group. We have to consider work, leisure, language and learning. We have to consider the group's reaction to disaster, delight, madness, impulse, discovery, boredom, birth and death – and all the other accidents of time experienced by man.

Social Organization

Organization implies both family organization (the people we are related to and the people we love), labour organization (who does what, and for how long), and social policing (defining and managing crime and conflicts, defining and managing the duties of the individual towards the "state" – or whatever we choose to call the collective of travellers. So this is the area of politics, social economics, and family life.

The complexity of the political and executive structure required by a group depends on the size of that group. The travellers are equivalent in size to a very small country – not a country as large and complex as China or the USA – nor even as large as Southern Ireland (Eire). China (with a population of more than 2E9) and the USA (with a population of more than 2.5E7) have organizational structures of great complexity, spread over many levels. The organizational structure of Eire (population below 4E6) has fewer levels, and is less complex. If we consider, to start with, a travelling population of 120,000 (1.2E5) – about the same population as *Saint Vincent and the Grenadines* – then the requisite complexity will be somewhere between that of Bermuda (population well below 1E5) and Samoa (population just over 2E5). Even if our travellers multiply to beyond 4E5 there will still be only as many as live now in Luxembourg[83].

83 If we get to the order of 8E5 we are in the range of Cyprus, Fiji and Djibouti. If we get to slightly over 1E6 (a million) then we are in the range of countries like East Timor, Swaziland, Mauritius, and Trinidad and Tobago, two million like Macedonia and Slovenia.

Governance

Layers of government will be required – though how many layers will depend upon the choice of the travellers. Some management experts point out that the Catholic Church – with an (estimated) membership of between one and two thousand million has just six (officially three) levels of organization over the laity[xxiv], whereas the Army has at least eleven[xxv]. If we consider that no individual officer should have control of more than five subordinates, then for a population of five hundred thousand we would have ten layers of control. The number of direct subordinates that a person can usefully control is also dependant upon the effectiveness of that individual as a manager – some can manage only one or two others, and some can effectively manage twenty. In practice there will be a spread.

If we consider that at the bottom level a manager can manage only two subordinates, at the level above three, above that four, and so on, then n at the lowest level means $1.33n$ for the two lowest together, $1.25{\cdot}1.33n{=}1.66n$ for the three lowest, $1.66{\cdot}1.2n{=}2n$ for the four lowest, $2.33n$ for the five lowest, $2.66n$ for the six lowest, $3n$ for the seven lowest levels. Already, with six layers of management over the lowest level, we have only a third of the population at the bottom ("doing the real work"), and two-thirds above it.

Level	Number managed	Factor	Total so far	Maximum Population
1	2	1.333333	1.333333	3
2	3	1.250000	1.666666	10
3	4	1.200000	2.000000	41
4	5	1.166666	2.333333	206
5	6	1.142857	2.666666	1,237
6	7	1.125000	3.000000	8,660
7	8	1.111111	3.333333	69,281
8	9	1.100000	3.666666	623,530
9	10	1.090909	4.000000	6,235,301
10	11	1.083333	4.333333	68,588,312
11	12	1.076923	4.666666	823,059,745
12	13	1.071428	5.000000	10,699,776,686

If we have fixed, smaller number of only four subordinates, then we have:

Level	**Number managed**	**Factor**	**Total so far**	**Maximum Population**
1	4	1.2	1.200	5
2	4	1.2	1.440	21
3	4	1.2	1.728	106
4	4	1.2	2.073	531
5	4	1.2	2.488	2,656
6	4	1.2	2.985	12,281
7	4	1.2	3.583	61,406
8	4	1.2	4.299	307,031
9	4	1.2	5.159	1,535,156
10	4	1.2	6.191	7,675,681
11	4	1.2	7.430	38,378,406
12	4	1.2	8.916	191,892,031
13	4	1.2	10.699	959,460,156
14	4	1.2	12.839	4,797,300,781
15	4	1.2	15.407	23,986,505,906

In actuality, we have to consider varying numbers – small at the low end, higher in the middle, and small again at the top. This may give something like:

There have been many forms of governance tried by mankind, and each seems to fit a particular world situation. In the case of the IT ship we have only internal affairs, and no external relationships – I think we can, with all probability, ignore the ship's encountering other intelligent life-forms on its journey. We have to ensure that we have justice, freedom, organization, equity and forethought. It is our habit, in the West, to assume that "democracy" is the only proper way – but by that word we each mean something slightly different.

We have the custom of placing ballots every two/four/five/more years for the second highest level of government (for example, parliament in the UK). Some countries also ballot for their highest level (for example, the President of the USA). The number and type of lower governmental levels for which ballots are cast vary greatly between Western countries. Each country can argue that its method is the best, or the best for it.

The manner in which ballots are counted also varies – first past the post, proportional representation, single transferable vote – and this also affects the nature of the elected bodies. And the manner in which candidates for election are chosen, or volunteer, and are permitted (or expected) to canvas differs too.

In some countries, opposing parties propose and fight for different resolutions, with very seldom meetings of compromise (such as in the UK): in other countries there is the tradition of coming to agreement by discussion, without any one party dictating what is going to happen.

In fact, no two nominally democratic countries use the same methods.

So what do we mean by “democracy”?

I suspect it is not possible for us to decide the governmental form for the IT Ship(s) – it is for their inhabitants to decide. There should be good instruction given, and carefully passed on, about the problems that we have found with different methods. But though we cannot decide for them, we can discuss it.

One instructive example from Terra is Venice. This city-state had both internal and external relations (so in that it differs from the IT Ships). It contained several conflicting sub-groups (factions) between which it was essential to keep the peace, in order to allow life in the city to continue. Venice, though, was not at peace – rule was kept by constant tension.

Iceland is a contrasting example.

<<<MORE HERE: VENICE, ICELAND

Religion

This is controversial. There is no decision that we can now make that will get universal agreement. The number of religions on Terra is huge – there are Christians, Moslems, Jews, Hindus, Sikhs, Buddhists, Taoists, adherents to Baha’i, Zoroastrians, Confucianists, Shintoists, Agnostics and Atheists – and many others.

It is probably impossible to collect a large group of people, and for a large group of people to live together, without religion being there, or subsequently appearing. This is discussed in more detail starting on page ?? below.

Ordinary Life

This is the day-to-day set of events to be expected – the ordinary work and play on board, the ordinary interactions between individuals and families and groups. It is also here that we have to consider the criticism "they will be bored out of their minds on this trip". Part of ordinary life is rest and recreation – entertainment and sport, sightseeing and art, looking at films and writing books, playing the guitar and singing in the church choir, flirting with pretty girls and growing better sunflowers than the neighbours to exhibit in the local show. On this ship all of these activities – and others like them – must be available. R&R is not just a part of ordinary life: it is an *essential* part of ordinary, healthy life. See the section on Culture, page ?? below.

Ordinary Extreme Situations

These are the limiting events such as birth and death, and minor catastrophes.

Extraordinary Extreme Situations

These are the massive catastrophes, and need only be considered if there are survivors.

Mood

The travellers will not be returning to Terra. That is a given. But they must not feel in any way second class. A settled group would not pine for the world they can never again reach, and would maintain optimism and pride onboard. Some geniuses will appear in the future amongst the travellers and by the force of their personal communication and management will impress but depress the society – *e.g.* Hitler, Stalin, Franco, Joseph McCarthy[84]. And also there will be positive geniuses, big and little, bringing society back up again, or persuading it to beneficial change – *e.g.* Nelson Mandela, Charlie Chaplin, Emmeline Pankhurst, Marie Stopes[85].

Our travellers need an initial organization that will encourage a healthy society, <<MORE HERE place, thought, freedom, culture, peace>>

Beauty of Place

Each place has its own beauty.

Leaving Terra brings loss of beauty – the beauty of the lands and seas we know, the beauty of the view we have of Sol and the near planets. On Terra, as you fly from airport to airport, you have the chance of seeing the patterns of the fields, and the interplay of the seas and land, and the inaccessible places which are cold and ruled by ice, and the forests that carpet the ground and brush with rocks and fields. All wonderfully beautiful, marred only by man.

As I write this paragraph I am in Swanage, Dorset, England. It is October in 2007 – Autumn, overcast and grey. I am looking out over the bay: to my left is the sea – sometimes tempestuous, sometimes rolling, now flat and smooth; to my right is the curve of the bay, edged with sand. The sky and the sea are almost the same pale blue-grey – perhaps the sea is slightly more green, or maybe I

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84 Why these names? They are people who by their actions (big and small) restricted life, liberty and freedom of expression in the 20th century. There were many more. Alas.

85 Why these names? People who by their courage and actions and talent improved life for millions in the 20th century. There were many more. Thankfully.

just fancy that it should be. The sea reflects the sky. Close to shore the sea reflects broken images of the low hills, and trees, and buildings. Beyond the bay, large boats move slowly between destinations that are not associated with me as I sit here. Some of my friends with me here say the view is dreary – yet it is beautiful in its own simple way.

This pattern of water and sky and land has all come about on Terra – and will not be reproduced on the ship. The ship will have its own beauty. This must be thought about, designed, crafted and maintained. Ugly conditions produce ugly behaviour – Oscar Wilde's observation that America was violent because it had such ghastly wallpaper was not just a flippant witticism. (Ref. [Wild1899] [Prin2001]) The ship's beauty is not Terra's beauty – for the travellers that is lost[xxvi] – but the ship's beauty must be created and considered and treasured. It is its own place.

Beauty of Thought

What is a beautiful thought? Philosophy, religion, sociology, medicine, psychology, politics and [teaching? Didactics?: NEED WORD HERE!] have different expressions for beauty of thought.

<<MORE HERE>>

Beauty of Action

<<references to religion? Does this belong with "beauty of thought"?>>

<<MORE HERE>>

Language

אַ שפּראַך איז אַ דיאַלעקט מיט אַן אַרמיי און פֿלאָט

A shprakh iz a diyalekt mit an armey un a flot.

A language is a dialect with an army and a navy.

Max Weinrieich (Ref: [Wein1945])

On Terra there are well over 4,000 human spoken languages[xxvii]. On the ship there will be, at the start, perhaps one hundred and twenty thousand people. It would be easy to have several languages simultaneously – if there were tranches of travellers originating from different branches of Terra's peoples, we could easily have, say, English spoken by 30% and understood by 45%, French spoken by 10% and understood by 15%, Mandarin Chinese spoken by 45% and understood by 50%, Spanish spoken by 30% and understood by 35%, and Russian spoken by 25% and understood by 35% – yes, the figures do not add up to 100%, as many people would start off speaking fluently more than one language. That is using just the UN official languages – but in today's world we have to change the mix, and consider Hindi/Urdu and Arabic/Hebrew as well in the mix, possibly dropping French.

But there's more here. If we allow different languages – without insisting on a single common language – then (a) we reduce the communication set for each individual (which had bad effects on the speed and flexibility of communication, and of maintaining the largest possible groups for group discussion [larger groups generally mean more or faster technical development], and (b) we set up an environment for possible future internal dissent ("my language is better than your language" "no it isn't" "yes it is" and so on, perhaps to conflict) – the forming of cliques.

If we do not allow different languages, and insist on just one core spoken language for the (first generation) of travellers, we will be losing a huge amount of Terra's culture. Goethe has a lot to say when translated into English – but how much better in German; Sartre reads well in English, but is more precise in French; and we lose such richness in translation – see Hofstadter's wonderful *Le Ton Beau de Marot* [Hofs1998].

We cannot retain all of Terra's languages onboard. If we restrict ourselves to just those languages that currently have more than fifty million native speakers we have 23 languages (see the tables below – estimates taken from [???] and [???]. The columns headed N are Native speakers, in millions, and the columns headed T are Total speakers, in millions).

Language	**N**	**T**	**Language**	**N**	**T**
Arabic	200	422	Mandarin Chinese	873	1051
Bengali	175	200	Spanish	350	500
Cantonese	55	90 ?	English	325	1100
English	325	1100	Hindi	250?	950 ?
French	65	500	Arabic	200	422
German	100	170	Portuguese	177	225
Hindi	250?	950 ?	Bengali	175	200
Italian	62	62	Russian	150	250
Japanese	125	130	Japanese	125	130
Javanese	75	75	German	100	170
Korean	67	75 ?	Punjabi	80 ?	105 ?
Mandarin Chinese	873	1051	Wu	77	77
Marathi	68	68	Javanese	75	75
Portuguese	177	225	Telugu	70	85
Punjabi	80 ?	105 ?	Marathi	68	68
Russian	150	250	Vietnamese	68	86
Spanish	350	500	Korean	67	75 ?
Tamil	66	72	Tamil	66	72
Telugu	70	85	French	65	500
Turkish	55	85 ?	Italian	62	62
Urdu	60	104	Urdu	60	104
Vietnamese	68	86	Cantonese	55	90 ?
Wu	77	77	Turkish	55	85 ?

Language	**N**	**T**
English	325	1100
Mandarin Chinese	873	1051
Hindi	250?	950 ?
French	65	500
Spanish	350	500
Arabic	200	422
Russian	150	250
Portuguese	177	225
Bengali	175	200
German	100	170
Japanese	125	130
Punjabi	80 ?	105 ?
Urdu	60	104
Cantonese	55	90 ?
Vietnamese	68	86
Telugu	70	85
Turkish	55	85 ?
Wu	77	77
Javanese	75	75
Korean	67	75 ?
Tamil	66	72
Marathi	68	68
Italian	62	62

So we have to consider some solutions. One solution is a forced (or evolved) common language, and another is an uneven balance. In practical terms (given Terra's current population in 2007) we will have to choose a small subset (two or three for the "uneven balance" solution, one for the "forced common language" solution) of languages from the set {English, Mandarin Chinese, Hindi, Arabic, Spanish} and insist that everyone speaks it/at least one of these. My personal opinion (=guess) is that the set will be English, Spanish and Mandarin Chinese – but I cannot foretell future history.

Language changes over time. There are many causes for change, including the need to talk about new topics, the meeting and merging of several cultures, changes in pronunciation over time (*e.g.* the Grimm Shift [REF]), poetic invention that enriches vocabulary and form (*e.g.* William Shakespeare for English), and the desire of each young generation to be different from its parents and each subgroup to be marked out by its speech as a “badge of membership” (*e.g.* the aristocratic slang of Jeeves in Wodehouse’s writings [REF], hippy talk, rap, rhyming slang, argot, baby-talk [that is the way in which adults talk to babies, and not the way in which babies babble – delightful and charming though that is!], poetic speech, technical speech).

One language change might be (and only might be) a merging of the most used languages of the construction community, to create a ship language which is an amalgam of … well, whatever languages are most used by the builders and scientists. And the final language on the ship, after several hundred years, is likely to be just that – something not known directly now, and emerging out of everyday practical use. The amalgam language is very likely to be a mixture of English, Spanish, Mandarin Chinese, Hindi/Urdu and Arabic – with French, German, Portuguese, Japanese and Russian influences as well.

Religion

*Ἐν *)en* p- -------- 1722 *ἀρχῇ a)rxh=|* n- ----dsf- 0746 *ἦν h)=n* v- 3iai-s-- 2258 *ὁ o(* ra ----nsm- 3588 *λόγος, lo/gos,* n- ----nsm- 3056 *καὶ kai* c- -------- 2532 *ὁ o(* ra ----nsm- 3588 *λόγος lo/gos* n- ----nsm- 3056 *ἦν h)=n* v- 3iai-s-- 2258 *πρὸς pro\s* p- -------- 4314 *τὸν to\n* ra ----asm- 3588 *θεόν, qeo/n,* n- ----asm- 2316 *καὶ kai* c- -------- 2532 *θεὸς qeo\s* n- ----nsm- 2316 *ἦν h)=n* v- 3iai-s-- 2258 *ὁ o(* ra ----nsm- 3588 *λόγος. lo/gos.* n- ----nsm- 3056 John 1:1 (with Strong's annotations)

There are no conflicts between religions. There are, however, strong conflicts, long conflicts and bloody conflicts between adherents of different religions, using the confusions of religion as an excuse (nominally "reason") for the conflict. There is no one decision in the design of the IT ship more difficult than this: what religion or religions should we permit the first travellers to hold?

Taking the religions with (currently) the largest numbers of adherents we have (in alphabetic order): Agnosticism (not knowing whether there is a God or not), Atheism (stating that there is certainly no God), Buddhism (in several varieties – at least three major), Christianity (in very many varieties – hundreds – and in three major forms: Orthodox, Protestant, and Roman Catholic), Hinduism (in a very large number of local forms), Islam (in two or three major varieties: Shiite, Sufi, Sunni), Other (for example the mixed-religion beliefs observed in hippies and isolated spiritual communities such as Findhorn, and Pantheism), Pluralism/Polytheism (simultaneous existence of several gods, not in the other categories), Shamanism, Shinto, Sikhism, Spiritualism. Most scientists and technicians, in Europe, fall in to one of the three categories Agnostic, Atheist and "Don't Care" – and this last is not a flippant addition, but a personal observation. In the USA there are a large number of (actually) atheist, or (actually) agnostic people that, for social reasons, declare themselves to be Christian.

My particular personal beliefs as an individual cannot be used to determine which religion or religions are to be permitted, as that would be a source only of conflict, and a restriction of freedom.

In Northern Ireland we have witnessed, up till the realisation of The Good Friday Agreement, an internal conflict which was interpreted as being Catholic v. Protestant. More sober analyses [REFS] showed this not to be the case: the conflict was very real and horrible, and the family backgrounds of *most* of the adherents to the two sides were as labelled – but actually the conflict was one arising out of economic differentiation, and external government. The British Army, for example, was fighting effectively on the Protestant side – even the Roman Catholic soldiers in the Army. In the USA we have seen tragic loss of life in acts of terrorism (*e.g.* The World Trade Centre – nine eleven), and disgusting maltreatment of prisoners of war, held without trial (*e.g.* Guantanamo Bay), and this is declared to be a conflict between Islam and Christianity. It is not. It is simply a political power conflict, in which the adherents to one side are, in the majority, *nominally* Christian, and the adherents to the other side *nominally* adherents of Islam. Quakers and Sufis despair of this sort of mis-identification [REF], and the vast majority of Christians and the vast majority of Muslims wish for harmony and peace [REFS], and do not agree that such a conflict exists[86]. In Russia we have seen, under Communist rule, a conflict supposedly between Christianity (usually, in that place, in the Orthodox variety) and Atheism (as decreed by The State) [REFS]. Again this is a mis-identification: it was, once more, a conflict between political control and church control, political control and personal freedom.

The travellers are human, and would be able to use religion, too, as an excuse or label for internal conflict. No matter with what religious structure we started, it would change over time. If the whole first generation were Atheists, belief would spring up over time; if the whole first generation were one particular brand of Christian, unbelief and difference in interpretation and change in belief would happen in time. We have to cope with this: the travellers have to cope with this.

One referee suggested sending the Christians and the Moslems on different ships – but that, alas, does not tackle the root problem. The root problem is that of man's intrinsic unpleasantness ("Man's

86 The name of Jesus occurs more often in The Koran than it does in The New Testament; and it occurs with high respect. Islam is *not* an enemy of Christianity.

inhumanity to man"[87]). All we can do is to set up a social organisation that highly values peace, social mechanisms for resolving disagreements without their escalating in to conflict, and strong education as to the consequences of physical conflict. Then we have to trust.

> 1 ἐν ἀρχῇ ἦν ὁ λόγος, καὶ ὁ λόγος ἦν πρὸς τὸν θεόν, καὶ θεὸς ἦν ὁ λόγος.

87 "Man's inhumanity to man / Makes countless thousands mourn." Robert Burns, *Mans Was Made to Mourn*.

Social Organization

Putting "Social Organization" as a branch of "Psychology" may seem slightly odd, but it can be justified. Psychology is about the behaviour of the human mind, and all the previous sections, on Mood, Language and Religion, have considered mental activities that have visible effects. Our social organisation is also a mental activity, resulting in visible effects. There are several levels of social organisation to consider: family structure, sexual organization, living patterns, regulatory structure, flexibility for change, degrees of free expression and secrecy permitted and expected, and the degrees and freedom of association permitted.

Family Structure

"Mummy, Daddy and two point three children" is not the only sort of family. We can have such "nuclear" families, and we can also have three-generation families, where the grandparents are considered part of the central unit. We can as well consider larger associations of, for example, siblings with their partners and children, together with grandparents as being the central units.

Some Terran societies use much larger groups – the clan or the house – as the main unit. These groups may contain many men – ten, twenty, thirty – of a range of ages, with their partners and children. Such groups of up to sixty people could also be considered the basic family unit. [REFS – Bruderhof, Papua/New Guinea]

And we can have smaller units too – taking the single parent family as the norm.

British people visiting France are surprised to see how the family unit there is so different from that normally experienced in suburban Britain – and these are two geographically close communities, with strong historical influences upon each other.

Sexual Organization

"Mummy, Daddy and two point three children" also presupposes one man in a permanent sexual relationship with just one woman. There is a frequent legal supposition that no persons under the age of sixteen (well, make that fourteen) engage in sexual activity. We know that this too is not the full range of possibilities – on Terra this is not what actually happens[88].

The sexual organisation, as part of the social organisation, of the IT travellers will, I suspect, evolve during the time of the ship's construction. We cannot, I think, determine in advance what it is going to be.

Living Patterns

"Mummy, Daddy and two point three children" is not the only pattern of living, because the living patterns depend upon the family units, the sexual organization, and the requirements of work and safety.

(details of housing, distribution of population around the habitable space, limitations on over-large gatherings, to avoid the risk of huge loss in the event of an accident)

Regulatory Structures

This is the large area ranging from "who organises sweeping the streets?" to "how are thieves prosecuted?". This is politics and government and the judiciary – politics, management and command.

Within every group of people there is politics. Sometimes this is just part of the job of management. Sometimes politics is the way in which opinion is managed to reach some end or other. Politics is entirely about people and opinion.

Within every group of people who have to stay together for a long period, and for whom there is a long-term aim, there is management. Management also involves manipulating opinions to the achievement of the ends – but more than politics, management involves the actual direction of people to do things.

Within every group of people living together there are necessary actions which are unpalatable or unsavoury or unwelcome to the person performing the action, but needed by the social group. For these actions there has to be control – control under command. This is stronger than management, in that it places the people

88 For example, the average age, *considered across the whole of Terra*, of the mother at the birth of her first baby was – less than twenty years ago – just fourteen. [REF – perhaps several ages and dates].

commanded under an obligation to perform the requested actions.

Within politics it is assumed that opinions change and associations are fluid – the opinions of the politician may be held with a greater good in mind, but the politician is recognised as having complete freedom of choice – even to the extent of choosing the ends themselves. Everything for a politician is negotiable.

Within management opinions are not so flexible. There is a fixed end stated, and the manager (and those managed) are working towards that end. The manager has limited freedom in his choices, and if the direction from above is unacceptable the managers – and those managed – have the freedom to part from the company (or whatever the managed group may be). Some things for a manager are negotiable.

Within command there is no freedom. Those directed under command must – irrespective of their own choice and wishes – perform the actions directed. Those who are commanded have no freedom to dissociate themselves from the command structure. Nothing for those commanded is negotiable.

In balancing rights and powers humankind has spent many centuries exploring different techniques. One solution suggested[89] is that freedom of choice should be inversely related to power. That is, the more powerful any social entity is the less choice it should have over its actions. Ultimately all groups have to report back to the whole population (in a democracy), through the loop {people, politicians, executive, implementers, people}. This loop introduces delay into the system – all large systems react to the situation as it *was* (or as it was predicted) and not as it actually *is*.

In Britain when I was a child and young, the Civil Service were referred to as Public Servants. Letters from the Civil Service to members of the public would be signed "I remain your humble and obedient servant". This did not stop the services from being rendered efficiently – but it did remind the actors who was really in charge – the people, articulated in the electorate.

In large societies – complete countries – we have parliament, the

89 and, ideally, actually used currently (the beginning of the 21st century) in the USA and the UK <<<REWORD THIS

civil service (which itself has several levels of freedom and of power), the judiciary, the police, the armed services. We also have, outside of the primary productive society, the academic tranche (who are essential for the continuance of the society at its level of civilization, and for the maintenance of technical knowledge), and the medical service (who, strictly speaking, are *not* essential – a society can live without doctors and nurses – but are greatly to be desired).

By using interlocking structures, with more than one reporting structure, more than one pyramid, we can help deflect the onset of tyranny. We cannot be sure that it will be avoided for all time, but in a small society (and fewer than one million people is a small society) there is too much family relationship throughout to allow an easy split into 'us' and 'them'.

Iceland has, at the time of writing (mid 2009) a population of about three hundred thousand (with an estimate of about four hundred thousand by 2050).

(Get details of population of Iceland – size, crime density)

(Get details of Mediaeval Venice governmental structure)

Change

"*The past is another country; they do things differently there.*"

L. P. Hartley [Hart1953]

There are many reasons for change in society. Some arise from new or altered pressures places upon the society, some from changes in technology, some from that society's choice of its organization and how it should be governed.

Change that is repressed can become explosive change when it happens. The longer a modification is restrained then, in general, the more painful is that modification when it occurs. Despite that, change has to be regulated and thought about. We want neither random change from day to day, so that people do not know or cannot be certain of what is expected now, nor the impossibility of moving from what has (in time) become unnecessary or unbearable or oppressive.

(Give examples of slow change, fast change, intermediate change.

UK form of government / education regulations in the UK / ?? fashion (in clothing, architecture)?? ??social attitude towards non-marital sex and/or homosexuality??) “Fashion is a form of ugliness so intolerable that we have to alter it every six months.” – Oscar Wilde).

Expression and Secrecy

Faustus: *I’ll burn my books! – Ah, Mephistophilis!*

Christopher Marlowe [Marl1604]

Freedom of expression is something we have come to take for granted. That freedom is protected by laws that limit the denial of that freedom, many different means of communication, and a social expectation of freedom. It is easy to pervert that expectation, and that perversion still happens in groups that take pride in their freedom. If I burn my books because I disagree with their content or think they are too dangerous, that is (perhaps) acceptable – I don’t think it is, but for the moment let us say this is (perhaps) acceptable [REWORD THIS!]. But if I burn *your* books or *their* books because I do not like what is expressed in them, then that really is not acceptable. Why might I burn your books? Because they suggest a political pattern I do not want [REF], because they suggest human interactions my religion or philosophy dislikes [REF], because they give you a freedom to think outside of the proscribed area the state / the church / the community sees as valid [REFS].

Faustus begged (too late) by his plea to be denied consignment to hell[90]. Yes, I can see that looks like a good excuse. But it is not. The work of Mephistopheles (Mephistophilis) is *by choice* in the mind: even if you are exposed to bad ideas you do not have to accept them. Counter bad ideas with good ideas, not by suppressing what you happen to believe are bad ideas. And what you think, or the state thinks, or the church thinks, or society thinks are bad ideas now, often turn out too be the good ideas and the accepted ideas at another time.

With the burning of books we have seen the tightening of Communist dictatorship (Russia and then the USSR [REF]), the

90 Marlowe’s Faustus, unlike Goethe’s Faust, receives no redemption.

imposition of Fascist dictatorship (Germany, Italy, Spain [REF]), South Africa's roughshod implementation of apartheid [REF], the expression of the KKK's "opinion" [REF], and other limitation of free thought in the USA [REFS] {Christian fundamentalist groups, Evolution, McCarthy Era}.

Information Storage

Books are long term. Short term are newspapers and magazines and their digital equivalents. Longest term are traditions. These are the way we store ideas across generations.

One of the most efficient ways we have found of saving information is making black marks on dead trees. Paper is efficient – though fragile. Stone lasts longer, but is far harder to copy. Paper, papyrus, velum, parchment, treated leaves, strips of bamboo – all of these have worked for extended periods.

We have several thousands of years experience with stone and papyrus, a few thousand with bamboo and leaves and parchment and velum, and at least two thousand with paper. We have only a small number of years experience with the digital media – fewer than seven decades for all of them, and fewer than three for most. We know that CDs are *not* a safe long-term store. There are at least two big reasons for this:

- Firstly the CDs themselves decay and they have to be copied and recopied to retain their contents.
- Secondly, the reading of CDs requires technology – it even requires technology to find out whether their contents have decayed or not. If the technology is lost, then the CDs are useless – even if their retention of data is perfect[xxviii]. With paper and papyrus (etc.) the only read-out and quality-inspection tools required are good ol' human eyes – and education and patience.

No matter what means of information preservation is chosen, the information has to be copied and recopied, to retain its integrity over time. Copying inevitably brings about corruption. There are techniques for minimising this corruption – witness the integrity of the Hebrew texts of the Torah (Old Testament) which have been copied by hand for hundreds – perhaps thousands – of years. These techniques are expensive (in manpower), and it is not worth expending this degree of effort upon all texts. A document which describes how to maintain, repair or operate a system upon which life depends – that is a document very definitely worth preserving carefully. A “bodice ripper” novel, very definitely not. Where on that line (of “worth it” / “not worth it”) we place scientific texts, the best literature and religious texts is going to the subject of heated debate – let’s not start that debate here!

Association

Physical Association

Freedom of association is something that many of take for granted. It was not always so – and it is not always so. There are sizes of groups that are dangerous, and sizes of groups that are familial. But upon what criteria – if any – should we limit association?

There is one good reason why we should have some limits on the ship – we do not want to lose everyone in a single disaster. We have to be ever conscious that this is not like England or Russia or Africa, each of which is very unlikely to be destroyed in a unique event[91]. A single shell penetration by impact may well destroy two areas on the ship – at the point of entry, and at the point of exit. So if (for example) half the ship's population were at the one point, and half at the other, then all are destroyed. Thus – like all things on the ship – the very largest group we should permit is one third of the ship's population in one place at one time.

Conceptual Association

The more important association is the association of minds. And there is no need to restrict this. This is where the nub of freedom of association lies: that people may freely communicate, all with all, every idea that they have.

Political Association is just one part of Conceptual Association. If we take it that freedom of expression is fundamental (and in historical experience it truly *is* essential) then we have to be sure that no political aims limit that freedom. Continued freedom of Conceptual Association is part of preserving that freedom.

<<<MORE HERE>>>

91 Note: only *unlikely*, not *impossible*: these countries and continents, and indeed the whole world, *will* be destroyed. That is, after all, one reason why we are building the ship.

Money

In all societies there are means of measuring exchange. Money is one method of both measuring and limiting that exchange. Requiring money to be given to initiate a (commercial) transaction means that money must be acquired. And if we make *useful work* one of the base items for which money is given, then we can perhaps ensure that some useful work is done. No society can simply live off its fat – the grain must be planted, the machines must be oiled, the vines must be pruned. Another acceptable base for money is *useful things*, and this goes alongside *useful work*. Luxuries exist and are also exchanged, but these must be eventually measured against “How much useful work is reasonable to exchange for this? What quantity of useful things is it reasonable to forgo for this luxury?”

On the ship the travellers can see the limits to their resources. There is no possibility of their acquiring more of anything. In this environment, money itself cannot be a source of money. If “wealth” represents something real, the absolute real quantities are, on the ship, known beforehand, with their limits. Wealth cannot continue to expand: this finite society in its finite environment simply has to live in balance – a balance of exchange: exchange of labour, exchange of goods, production and management of essential products and facilities.

This balance of exchange is well known by many pre-industrial societies here on Terra. These groups ensure that we get “from each according to his ability” and in return “to each according to his needs”. This Marxist [Marx1875] dictum does *not* mean that there is no private property, nor does it mean that “The State” must control everything. It *does* mean that we can support no wastrels, and that no-one is denied a quality of living and support comparable with everyone else. This essay is not the place to compare the economics of the whole of Terra with those of the ship – even though the same truths hold.

The unit of currency will be new, and it representation anything the travellers find convenient – if, indeed, a physical representation is needed. Wealth measured in “number of cows” slews the use-fulness of cows, impacting food production. Wealth measured in “number of cowry shells” is (IMHO) better, as cowries have no direct usefulness, except as decoration. Wealth measured in “ounces of gold” worked very well here – but we have to be sure that this does not interfere with the proper engineering and decorative uses of gold.

Wealth to which a number is given, and exists *only* in the abstract is dangerous. The numbers can continually increase, without anything real being created. Financial interest (usury) can get out of hand, and the value of the “currency” will, at some point, crash. We have lots of prior examples here on Terra, and we are, sadly, building up to another major – catastrophic – collapse of *all* the Western currencies simultaneously. This will be a loss of confidence in the systems that generate such huge excesses of wealth from *no* useful work, and such imbalance. Some of that imbalance is global, and some is visible in just a single country – any country. One percent of the world’s population own 40% of the household goods.

Costs

"The world today [1988] spends $1 trillion [USD] a year on military preparations... That trillion dollars a year takes food from the mouths of poor people. It cripples potentially effective economies. It is a scandalous waste, and we should not countenance it."

Carl Sagan (Ref: [Saga1988])[xxix]

Introduction

There are two major sources of cost that we have to consider – the positive costs of doing the research, development, construction and launch of an interstellar vehicle (or vehicles), and the negative costs of not undertaking this adventure.

Firstly we will have to consider the scale of the project – what magnitudes of costs are we going to be considering.

We will then look at the negative costs – that is, the costs of not doing interstellar travel. We will show that these costs are so horrendously high that almost no matter what the positive costs are, they have to be born.

In evaluating the positive costs, we are assuming (approximate) 2003 figures, and using US Dollars. The actual figures of the project when (if?) it happens will be very different, because of inflation (which, for the moment, we have ignored), greed (for which we cannot estimate), and happenstance (for example, we cannot really know, in advance, exactly how complicated some of the development will be). But the estimates we make here should give us an idea of the scale, and what we have to invest in, economically, to get this project going.

And finally, as well as these direct costs, we have to consider the economic and sociological impacts of such a large project. Unless mankind can accept these impacts, the project will not be competed or maybe not even started.

Scale

When we look at the scale, we can see it is truly enormous – the largest technological project mankind has ever undertaken. I am suggesting – seriously suggesting – that we invest some 8% of the world's GDP[92] (which equates to more than 10% of the world's productive workforce) on this one project. As a comparison, consider that the current government in the USA spends some 25% of the GDP it doing what it does, and that 3.3% of the GDP of the USA[93] is involved in just one area – defence.

This project is not 3.3% of the USA, but 8% of the world. It is a project requiring, for its organization and management, at least three layers of command greater than that required by the military. Organizational costs, therefore, will also be a huge factor – and a very large part of the project's fiscal costs.

World, not country. So there has to be a true international impetus, and (therefore) international management of this project. Projects very much smaller than this breed corruption – that, too, will have to be managed. Large projects have political effects – that is another aspect that has to be considered, and contained.

In 2005 the GDP per capita of the USA was quoted as well over $39,500. If we move forward four decades and assume as the mid-line (for initial argument) that (a) there are *at least* 10 thousand million people in the developed art of the word, and (b) the GDP of that part of the world is $20,000 per capita, then we are considering a project of the order of 10% x 1E10 x $20,000 = $2E13 per year for 100 years = $2E15 (minimum). This is *not* a small project.

At the upper end, we can consider ten times this – that the number of people is greater than 1E10, and that the GDP is greater than $2E5 – so that if we consider just half of 4E10 people[94], and an average GDP (for that half) of $3E5[95] we have the project (which we take to be 10% of the total GDP) as $1.2E14 per annum, or

92 Gross Domestic Product = "the total value of final goods and services produced within that territory" [Wiki2005a]

93 According to CIA figures for FY 2003 (February 2004 estimate)

94 This is a high, but by no means impossible, figure.

$1.2E16 over the hundred year period – six times as much as the mid-line.

At the lower end we can suppose that somehow (somehow!) we will manage to control human population, and that in four decades there will be just 7E10 people (seven thousand million), and that 2.5E9 (two thousand five hundred million) of them have cash to spare – that these are the people in the wealthy "first world". If, again, we assume that the GDP of that part of the world is $20,000 per capita per year, and that we can take 10% of this for 100 years then we have a total of $5E14 – a quarter of our mid-line figure.

To justify a project lying within this economic window of [$5E14,$1E16] we have a lot of measuring to do! The lower figure in this range is more easily "justifiable" (from the point of view of future projected populations and economic growth) than the upper. If we consider the year 2050 AD as being our starting point, and a world population then of 1E10 (ten thousand million), of whom half (initially) are able to contribute 10% of their $20,000 GDP, then we can take $1E15 as our central point, and consider the window from half of that to five times that, which gives us [$5E14,$1E16] as our realistic window. <<<REPHRASE

To offer another comparison, the GDP of the Russian Federation was estimated, in 2004, to have been $6.18E11. World defence expenditure [2004] is estimated as being $9.5E11 – hence the USA is involved in more than half the whole world's military expenditure.

95 This also is high – and we would very much like to live in that kind of a world, according to our capitalist thinkers! Real – ordinary – people largely have other views.

Negative Costs

There are two certain causes of human annihilation that face us: overpopulation, and destruction of Terra. We consider these in turn, together with some equally nasty, but not certain, possibilities – each of which results in the complete extinction of mankind.

Overpopulation

The numbers of mankind on this planet are growing. The numbers cannot grow for ever. We have only a finite amount of resource to feed ourselves, and sustain ourselves, and when that is all used up then we can grow no more.

Inevitably, we must reach zero population growth. We probably have to reach negative population growth. We do not, in the near future, and for reasons we could avoid, want to experience explosively negative growth – the annihilation of the whole of mankind – but given our current access to technology, that too is a possibility.

The spread of material wealth is very uneven. There are those countries (often called the "developed" countries) that have adequate resources to feed, cloth and maintain their populations. These countries have modern health care, long life-expectancies, and good education. They are comfortable countries. And there are those countries, euphemistically called "developing" countries, which have perhaps nothing, or next to nothing. In these countries life expectancy is low, poverty is high, health care meagre or non-existent, and education sparse. These are the countries whose population growth is the greatest. Where there is the greatest need, there is the greatest growth. We are starving ourselves to death.

With more people, there is more pressure on the world's natural resources. We are annihilating species[xxx], we are destroying ancient environments upon which other species depend, and threatening to extinguish those species too. The world population figures are horrifying, and the world pollution figures are horrifying. We are tampering with the ecology[xxxi], with the climate[xxxii], with the balances of natural resources[96].

96 Hurricane Katrina (August 2005), which so devastated New Orleans, was just one illustration of our vulnerability.

And we are not going to get away with it. If we do not reign back, then we are doomed – quickly doomed[xxxiii]. Yes, we can anticipate another eight million years of humankind, based on the observed laws of genetics and evolution. Yes, we can anticipate a habitable planet for more than 750 million years – perhaps even 5,000 million years, based upon the observed laws of physics in our nearest star, the Sun (Sol). But, no, we will extinguish ourselves within at most 250 years if we continue to grow at our current rate.

This is not "perhaps" – this is definite. If we do not reduce our population growth soon, we are doomed. We probably also have to reduce our total population – we have got to achieve zero population growth: arguably, we need some negative population growth as well.

Our Growth Patterns

Mankind breeds energetically. This is true for all successful species, but in Nature there is a long-standing balance between the predatory (and natural) losses on a species, and its growth. Natural equilibrium, for a species, means that roughly as many are born in any year as die in that year. There will, of course, be periodic oscillations – but century-by-century, little change.

Not so with mankind. We are growing all the time. We are modifying our environment to be less hostile to us (and, frequently, more hostile to other species). We are making medical advances that both prevent young children from dying, at the low end, extend our life-spans, at the high end.

We do not replace just the number that die: we replace for every thousand deaths about one thousand and fifteen new human beings. We are doing this year after year, century after century. We now count our population in thousands of millions.

The observed population growth, with some future estimates, are shown in the following graph:

From this we can see that we have passed, and are predicted to pass the incremental thousand-millions in the following years:

1,000 Millions	**Year**
3	1960
4	1974
5	1987
6	1999
7	2012
8	2027
9	2048

These estimates, though, rely upon our reducing the growth rate. At just 0.2% above the current growth rate of 1.25% per annum, giving 1.46% per annum (which we are in real danger of achieving soon) – and making no extra allowance for the increased number of breeding-age people – the future years of crossing the thousand millions are:

x10^9	**Year**	**x10^9**	**Year**
6	1999	16	2067
7	2010	17	2071
8	2019	18	2075
9	2027	19	2079
10	2035	20	2083
11	2041	21	2086
12	2047	22	2089
13	2053	23	2092
14	2058	24	2095
15	2063	25	2098

If we do not cut back our birth-rate, and carry on just as we are now, it is this following (horrifying!) table that contains the figures for our future population sizes. This assumes a constant growth rate of 1.25% per annum – out current growth rate:

Year	**Pop.**	**Year**	**Pop.**	**Year**	**Pop.**
2006	6.50	2022	7.93	2038	9.67
2007	6.58	**2023**	**8.02**	2039	9.79
2008	6.66	2024	8.12	2040	9.91
2009	6.74	2025	8.23	**2041**	**10.04**
2010	6.83	2026	8.33	2042	10.16

2011	6.91	2027	8.43	2043	10.29
2012	**7.00**	2028	8.54	2044	10.42
2013	7.09	2029	8.65	2045	10.55
2014	7.18	2030	8.75	2046	10.68
2015	7.26	2031	8.86	2047	10.81
2016	7.36	2032	8.97	2048	10.95
2017	7.45	**2033**	**9.09**	**2049**	**11.09**
2018	7.54	2034	9.20	2050	11.22
2019	7.64	2035	9.31	2051	11.36
2020	7.73	2036	9.43		
2021	7.83	2037	9.55		

And the real picture is even more grim. Though the developed countries are cutting back their growth the developing countries are lagging severely.[xxxiv]

If we assume that population growth itself grows at just the tiny 0.002% per year[97], until world population is 15 thousand million, and then falls back again at the same rate until growth regains the value of 1.046%, then the years are: >>>RECALCULATE>>>

1,000 Mlln.s	**Year**	**1,000 Mlln.s**	**Year**	**1,000 Mlln.s**	**Year**
6	1999	34	2042	61	2080
7	2007	35	2043	62	2081
8	2011	36	2045	63	2082
9	2014	37	2046	64	2083
10	2016	38	2047	65	2084
11	2018	39	2049	66	2086
12	2020	40	2051	67	2087
13	2021	41	2053	68	2088
14	2023	42	2054	69	2089
15	2024	43	2056	70	2090
16	2025	44	2058	71	2091

97 So growth in the first year is 1.046%, in the second it is 1.048%, in the third it is 1.050%, and so on. In the current example it rises to only 1.064% (which is much lower than the rate many countries already experience, over long periods), then falls back, regaining 1.046% by the year 2047.

17	2026	45	2060	73	2092
18	2027	46	2061	74	2093
19	2028	47	2062	75	2094
20	2029	48	2064	76	2095
21	2030	49	2065	77	2096
22	2031	50	2066	78	2097
23	????				
24	2032	51	2068	79	2098
25	2033	52	2069	80	2099
26	2034	53	2071		
27	2035	54	2072		
28	2036	55	2073		
29	2037	56	2074		
30	2038	57	2075		
31	2039	58	2077		
32	2040	59	2078		
33	2041	60	2079		

These tables show that we simply do not know as to whether on my hundredth birthday, in 2045, there will be 8.9 or 11.5 or 36 thousand million people on the planet. What we *do* know is that – barring terrible disasters – population will be much greater than the current (about) 6.5E9. *All* of these figures are too big for comfort, too big for health, too big to sustain[xxxv]. All of these figures show how we are raping Terra, killing Terra.

But in places – many places – on Terra we already sustain a growth rate much larger than any we have considered in reaching these figures. There are many countries whose population grows at more than 3% per annum. If we let the whole world behave like that, then the figures would be: <<<RECALCULATE<<<

1,000 Mlln.s	**Year**	**1,000 Mlln.s**	**Year**	**1,000 Mlln.s**	**Year**
6	1999	29	2053	59	????
7	2005	30	2054	60	2077
8	2009	31	2055	61	2078
9	2013	32	2056	63	2079
10	2017	33	2057	65	2080
11	2020	34	2058	67	2081
12	2023	35	2059	69	2082

13	2026	36	2060	71	2083
14	2028	37	2061	74	2043
15	2030	38	2062	76	2085
16	2033	39	2063	78	2086
17	2035	40	2064	80	2087
18	2037	42	2065	83	2088
19	2038	43	2066	85	2089
20	2040	44	2067	88	2090
21	2042	46	2068	91	2091
22	2043	47	2069	93	2092
23	2045	48	2070	96	2093
24	2046	50	2071	99	2094
25	2048	51	2072	102	2095
26	2049	53	2073	105	2096
27	2050	55	2074	108	2097
28	2052	56	2075	111	2098
29	2053	58	2076	115	2099

So, well before the turn of the next century, we would have many more than one hundred thousand million people, just by using the birth-rates already experienced in Angola, and Mozambique, and Nigeria, and Ethiopia, and Congo, and …

Cynical though it seems, I think it unlikely that we will really control world population growth by anything other than war and natural disaster, for the next 50 years. We are going to reach 15 thousand million[98] before the year 2063 – and that will starve us.

The figures from the United Nations (as quoted in [Ref:????]) are, in my opinion, over optimistic. They imply an imminent slackening-off of growth, and our not reaching seven thousand million until 2013, eight in about 2027 and nine in about 2052. As I write it is 2007, and we are on target for seven thousand million in early 2012, eight in 2023 and nine in 2032.

The following diagram illustrates our uncertainty expressed in the above tables. It shows the world's population (in thousands of millions) against the expected date of our achieving that. IMHO the top line is too horrifying to contemplate – and cannot happen (there would be breakdown too soon for that); the lowest line is

98 Or 37 thousand million or 46 thousand million or …

overly optimistic, but the middle, red line is what will happen unless we take strong positive action to prevent it. (We cannot take seriously the optimism of the U.S. Census Bureau – graph on page Error: Reference source not found above.).

World	*0-14 years:* 29.6% (male 933,647,850; female 886,681,514) *15-64 years:* 63.4% (male 1,975,418,386; female 1,931,021,694) *65 years and over:* 7% (male 188,760,223; female 241,449,691) (2001 est.)
United Kingdom	*0-14 years:* 18.89% (male 5,778,415; female 5,486,114) *15-64 years:* 65.41% (male 19,712,932; female 19,304,771) *65 years and over:* 15.7% (male 3,895,921; female 5,469,637) (2001 est.)
United States	*0-14 years:* 21.12% (male 30,034,674; female 28,681,253) *15-64 years:* 66.27% (male 91,371,753; female 92,907,199) *65 years and over:* 12.61% (male 14,608,948; female 20,455,054) (2001 est.)

Death Rates

World	8.93 deaths/1,000 population (2001 est.)
United Kingdom	10.35 deaths/1,000 population (2001 est.)
United States	8.7 deaths/1,000 population (2001 est.)
Libya	3.51 deaths/1,000 population (2001 est.)
Angola	24.68 deaths/1,000 population (2001 est.)

((**In 2006** the mean age for giving birth was 29.2 years, whereas in 2001 it was 28.6 years of age. UK)) ((Despite the high rate of teenage pregnancy in the United Kingdom, there is an overall trend towards later childbearing. In England and Wales the average age of mothers at childbirth has increased by three years since 1971, rising from 26.2 years to 29.1 years in

2000. Over the last decade the average age of women at the birth of their first child has risen by one and a half years, to reach 27.1 in 2000. Information on the average age at first birth over the last 30 years is only available for married women. The average age of women giving birth for the first time inside marriage has increased by almost six years since 1971. Births outside marriage tend to take place at a younger age than those inside marriage.))

Modifying Growth

Tiny changes in birth-rate have big effects on world population. As an example, in the following graph there are two population lines: the upper one is for a continuous growth rate of 1% (smaller than we currently experience), and the lower one – which eventually starts to decline – is for an oscillating – but falling – growth rate (left vertical axis is thousands of millions, right vertical axis is population growth rate, horizontal axis is years since 1998):

Since overpopulation will kill us, we have to modify our birth-rates, our population growth rate. This is an essay on Interstellar Travel, and not on world population control – so I will not go into the various techniques here. There are many web sites and paper publications about world population growth and its ecological impact – I refer you to those. Just remember: the world is finite, the most populous areas are those that are growing fastest, there must be a limit – and reaching that limit will be nasty, and utterly terminal. Systems do not have to collapse gently – they can and do collapse catastrophically (like the destruction of Easter Island's trees, previously mentioned).

Since we are (as a species) so intent upon killing ourselves on our home planet, we should – we must – *urgently* – consider getting some of us off this dying planet and far enough away from its current state to survive, no matter what. And we have to act right now on world overpopulation.

Because of the urgency of dealing with world population, and the severe pressures that overpopulation is going to place on mankind[99], we have only a short time in which we can commence such a hugely expensive project as the interstellar ship. If the world's population is going to be, in fifty years, at least nine (or 12 or 27 or 40 or …) thousand million, then we will experience heavy – crippling – financial pressures in feeding ourselves. These pressures will (very likely) prohibit us from expanding outwards from this planet as we know it. It will be considered too expensive, with thousands of millions of starving people on the (dying) planet.

We have at most 50 years in which to get this project under way, so that it can (perhaps) then run with the momentum of an existing project. In the next half century let us firmly grasp its necessity and overcome the obstacles which a new project always faces.

Destruction of Terra

There are five sources for the destruction of Terra (or rather, of the biosphere) that I will consider here:

- Doing nothing, and choking, irradiating and polluting ourselves to death (the "poison fog"),
- Accidental release of a destructive agent, or natural evolution of a highly destructive, contagious disease (the "grey goo" or the "black death"),
- Nuclear war (the Big Bang)
- Severe impact by an interplanetary body (*e.g.* very large asteroid or comet) (the Even Bigger Bang)
- Total destruction of the Earth (Terra) by the Sun (Sol) going nova (the Biggest Bang of All).

We will consider each of these separately, evaluating its severity and probability of occurrence. And to this list you could add more possibilities, not listed here, of various degrees of likelihood from "possible" down to "extremely implausible": (*e.g.* massive volcanic activity – such as Yellowstone pouring out pyroclastic flow, or overall genetic weakening – so we become less able to breed and survive, or invasion by aliens – "little green men").

99 *Already* places on mankind – and all other lifeforms too.

Poison Fog

This is not *really* about poisonous fog – even though we do produce vile corruptions of the atmosphere. We are polluting the atmosphere, the soil and the water. We are irradiating ourselves, transmitting many signals on a variety of wavebands (radio, television, radar, etc.), and generating so much light at night that in many places the sky is never black.

We have shrunk the available environments for many species to the point of annihilation. For example, we have – in just one century – increased the amount of Carbon Dioxide (CO_2) in the atmosphere by 25% (Ref: [Epca2005]), or by about 40% since the start of the Industrial Revolution[xxxvi]. We extinguish – make extinct – at least one species of living creature per day. There is nothing that prevents humankind also from being on the list of endangered species.

With the coming on-stream of China as a technologically developed nation, burning more fossil fuels to generate its power, we are going to make Terra even warmer, and even more clouded in smog and carbon dioxide (and all the other many industrial pollutants).

This pollution is now – probably – unavoidable. We cannot stop developing countries from developing. We *can* devise less harmful technology, and we should be seriously looking at this, at an international level.

Grey Goo or Black Death

Nano-technology is (amongst other things) the study of producing extremely small machines. These could be, for example, robots that perform some useful task. One of these useful tasks would be self-reproduction – if you have a useful machine, you would like to be able to make many copies of that machine – and a self-reproducing machine looks like an ideal candidate.

The “Grey Goo” fear is that some such nano-machine will be constructed which reproduces itself, using available carbon and oxygen and nitrogen (etc.), and that this machine might not be able to be controlled. Once such a culture has “escaped” it would begin converting all convenient “packets” of its building-blocks into copies of itself. Human beings, fields of grass and corn, blue whales, oak trees and cabbage patches – with all other living things too – are convenient “packets” of raw material. Such a culture would gradually take over the whole biosphere, reducing everything to a “grey goo”.

One form of nano-technology is genetic manipulation. Imagine, for a moment, a misdirected scientist who manages to harness the infectiousness of smallpox to the mortality of Ebola, or mixes the air-droplet spread of influenza with the deadliness of AIDS … such an organism would have a devastating effect upon humankind, potentially annihilating the species. This would be the “Black Death”.

You may be happy that such a mad scientist could not now exist, or that he would be quickly caught before his deadly work escaped – but in a world of six thousand million people can you be sure? Would you be more sure or less in a world of fifteen thousand million, or thirty, or one hundred thousand million? Man’s inhumanity to man is startlingly vicious – I would not bet on it.

I cannot estimate accurately how likely the “grey goo” or the “black death” are – but I would give a ball-park figure of 30% probability of one of these happening within the next 100 years. This is only a guess – but a depressing guess.

<<<<REFERENCES<<<<

Grim, but possibly – with policing – we can avoid this.

Big Bang

We are never going to blow ourselves up, are we?

Don’t be too sure of that.

We used, most of us, to think that nuclear reactors were safe – always being managed by educated and careful scientists – until we encountered Three-Mile Island and Chernobyl. The H-bomb may be converted into *The Sword of Islam*[100] or *The Stone of Zion*[101]

100 True Islam is the noble religion of peace and truth and submission to The Highest.

or *The Hammer of the Sikhs*[102] or *The Blade of Christ*[103] or *The Spear of Truth*[104] by some misdirected fanatic, quasi-religious or political group (and experience teaches us that there are many such fanatics in the world[105]). Almost any nuclear installation round the world may go unstable. Almost any nuclear weapon round the world may be purloined, or accidentally ignited – though some are more vulnerable than others.

Creating nuclear weapons is not difficult. Creating *efficient* nuclear weapons, without killing the people that put them together, *is* difficult – but lunatics and the power-hungry do not care about that.

We have already – twice – used nuclear weapons upon people (Hiroshima and Nagasaki), and we are perfectly capable of doing so again.

I would estimate another 20% probability that there will be another major nuclear accident within the next 100 years, affecting a considerable proportion of human life.

<<<<REFERENCES<<<<

Very grim, but possibly – with education – we can avoid this.

Even Bigger Bang

This, if it happens, is something we cannot currently avoid. If a

101 Real Judaism gives perfect respect to The Almighty, honours real knowledge gained through study, and strongly encourages social care, starting from the family and moving outwards.

102 Sikhism shows us courage, and mutual care, familial love and honour for truth.

103 Christianity at its core show us universal love and respect for all creation: Christ instructed us to love everyone, and showed in His submission just how far Love can go.

104 “What is Truth?” John 18:38. Pilate’s question. Every child’s question.

105 An inexhaustible supply of fanatics is, it seems, man’s gift to the universe.

rock the size of *1 Ceres* or Phobos were to hit Terra then mankind would certainly be annihilated[106]. A much smaller – and hence more likely, more common – rock would have the same consequence – annihilation. The nasty side of this disaster is that we would be annihilated slowly, over the months, starving to death. A large impact[107] would initially have a major effect upon ocean levels, and cause devastation near the coasts, which would kill a large number of people in the first strike. There would be survivors. But thereafter the world's climate would have changed, and there is a very good chance that we could no longer grow sufficient – or perhaps any – crops to sustain ourselves, the survivors.

Although we are looking at the skies to detect forthcoming strikes, we are not yet sure that we will detect all such strikes prior to their happening – we are still "blind-sided" by objects coming from the (apparent) direction of Sol – we might get just eight minutes warning of the forthcoming end of life on the planet.

Meteor and asteroid strikes have happened before on Terra, and – we are fairly sure – have already been the cause of major biological catastrophes. The most recent major impact, for example, may have been that which caused the end of the age of dinosaurs, and which removed over 90% of the species on the planet (not just 90% of the individuals – 90% of the *species*, of the varieties of life!). An earlier impact wiped out 98% of the species[108].

<<<<REFERENCES<<<<

Extremely grim, and unavoidable, with provenance – but of utterly unknown probability.

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106 There is a possibility that we could shift some approaching rocks of a smaller size, given long enough notice – but something more than 20 km in diameter is beyond all possible management. Such a rock would be inevitably fatal.

107 A "large enough" impact would be total and sudden annihilation – this would be impact with an object, say, 100 km in diameter. This is a very unlikely size to hit us – but smaller rocks hit us all the time, from sand-grain size particles upwards.

108 And that – it is thought – was an object *less* than 10 km in diameter **[Ref: ???]**.

Biggest Bang of All

Sol *will* go nova. We are certain of this. What we are not certain of is exactly *when* it will go nova. We suspect that we have at least 5,000 million years and no more than 5,500 million years.

Unlike the other devastation scenarios, this one is complete, and this one is certain. We have a 100% probability of this occurring within the next 6,000 million years.

<<<<REFERENCES<<<<

Totally grim, unavoidable, and certain.

Conclusions

So, I have shown that we are doomed. But don't take this personally – there is a way out, and (in any case) the doom is not so soon that you cannot make plans for next Christmas, next Hanukah, next Divali. But it is certain that unless we do something to save mankind, then there will be no more mankind. So let's do something about it.

We do not have long to start this project – at the very most we have 50 years to be well under way, with the aim of launching[109] at most 100 years from now. If we wait longer than that, we will not be able to afford it, and it will be too late for the species.

109 Maybe not launching the final ship – perhaps that will take longer – but at least the first experimental prototype at (say) the distance of Pluto orbit.

Positive Costs

These are the costs of designing, building, equipping, and launching a ship or ships. The costs must be split up into the one-off costs (which are a flat base, no matter how many ships are subsequently built), and the per-ship costs.

We consider the following costs:

Heading	Description
Education	These are the costs of getting the politicians to buy in to the project. These are imponderable – but necessary – costs. If the politicians are not convinced, the money will not be available. There is no single businessman or world corporation with sufficient economic power to make this decision – it has to be a planetary or state decision[xxxvii]
Research	These are the initial, one-off costs. After the launch of the first ship there will still be research, but that will be only incremental research to improve upon the initial design. These costs are very front-loaded for the whole project of building ships. No matter how many ships are built, these costs are (largely) the same.
Development and Design	These are the costs of building prototypes, and running them for a while, and constructing the resultant design for a real ship. These costs are also front-loaded, but some part of these costs will occur for every ship built, if its design is not identical to a previous ships.
Building and Equipping	These are the costs of building a single ship. They occur exactly once for each ship built, They depend upon the size (the scale) of the ship being built.
Launching	The launch costs are those of choosing the right people and waving goodbye to them.

These costs will include the long-term support costs for each ship. These long-term support costs can be completely avoided, if we decide not to communicate with our interstellar ships after we have launched them, but we would probably decide to listen to what the travellers have to say, and let them share with us what they have discovered, and *vice versa*. These costs need to be considered per ship for up to 100 years after the launch of each ship.

We need to consider all these costs also in the light of existing costs of space exploration.

>>> Cost of Shuttle $\$2.1\cdot10^{9}$ ($2.1E9)each

Cost of Shuttle Launch $\$470\cdot10^{6}$ ($4.7E8) per launch (say $\$5.0\cdot10^{8}$ ($5E8)– half an [American] billion dollars) **<<<MORE HERE <<<**

“We can’t even spare 8 x 10^9 dollars on a nice particle accelerator, let alone what it would take for a moon-shot. The Apollo program cost 25 x 10^9 dollars 30+ years ago [nationmaster.com].” (Quote from Slashdot, 20040116) This means that a repeat program would cost at least $\$6.0\cdot10^{10}$ ($6E10) now (at only 2.5% inflation – a low estimate) or (more likely) $\$1.5\cdot10^{11}$ ($1.5E11).

Education

We have to get the project off the starting blocks. This means making people want to do it. Not just a few people – a lot of people. Ideally (though this will never be achieved) the whole human population should want to take part in this project, or consider it worthwhile. At the very least, a majority of the economic power of the world should accept the project as worthwhile, and be prepared to invest in mankind’s long-term future. This means getting the politicians interested. And it means getting both ends of the political spectrum agreeing with the expenditure. All the parties (or many of them) have to convince the people – the voters – that this is worth doing.

This is the hardest step of the whole project. I do not have to convince those readers who are already engineers that politicians are (usually) a waste of intellectual space. Those who are not (or were not) are notable, and remembered. Interstellar travel is not (as yet) a vote winner, so despite its being extraordinarily important for the long-term survival of humankind, it does not interest politicians (as yet).

We have to have the people that can do the design, do the building, construct the necessary environments. These are the engineers – and we will need a lot of them. We have to educate the engineers – if the politicians are willing to put the money into the project, this is "easy" (but not quick). It takes at least twenty-five years to produce a useful change in the number of technicians in a society[110]. If we are to start work on the interstellar ship within 50 years, we have only 25 years in which to persuade the politicians, so we can start producing the engineers in time.

If we assume that we need half a million engineers worldwide, working for a total of 50 years to produce the first ship, then we have to consider the educational costs of half a million dollars per engineer, and wages of (say) one hundred thousand dollars per engineer per year, with each engineer having a productive working life of 40 years. This gives us:

Education	$5.0 \cdot 10^5 \cdot 5.0 \cdot 10^5$	$2.5·$10^{11}$
Wages	$5.0 \cdot 10^5 \cdot 40 \cdot 10^6$	$2.0·$10^{11}$
Total		**$4.5·$10^{11}$**

Research

Research, in this context, means finding out how to build an interstellar ship, how to power it, how to construct the base mechanisms we are going to use. Research means getting money from governments to build rockets and space elevators and train astronauts. Research means thinking about how to propel extremely large lumps of matter through space. Research means

110 And once you have those technicians, you have them for another 25 years – a good investment. But now – in 2004 – we are beginning to run out of the technicians we created in the 60s "Space Race".

setting up self-sufficient biomes here on Terra, and then research means going to the Moon (Luna) and setting up self-sufficient biomes there as experimental stations. Research means finding out how to construct long-chain fullerenes, or manufacture strong fibres (*e.g.* carbon mono-filaments – see [Edwa2003]), or build tiny reactors, or launch into orbit cheaply. Research means all kinds of investigations that we have not yet imagined. Research means effort.

It would be dishonest of me to pretend that this is anything other than guesswork on my part. Research is always looking into the unknown. We can only guess what the costs will be.

??5.0E+13??

Development and Design

Under "Research" we have not considered building the first prototype, and we have not considered building the Space Elevator. Both of these (IMHO) are necessary, and are considered as part of the Development phase. And, of course, we have to design the ship.

Space Elevator

To create the Space Elevator needs both materials research and engineering design for fail-safe transport. This group of problems is well documented and being actively researched: for the initial description see [Edwa????] and [Edwa????a], and the links from web sites such as [REFS.].

Prototype

Ship Design

??5.0E+13??

Building and Equipping

Building the ship is the longest phase. We have to transport into space all the material that we cannot construct from existing space material, the initial stock of people, the biological material, the elements that we cannot easily get in space, and the initial cargo (the works of art, machinery, books etc.) that we want to carry with us.

Building the ship means finding an asteroid, turning that asteroid into a viable biome, installing the huge amounts of machinery needed to move and support ten thousand people for ten millennia, spinning the asteroid to give it internal pseudo-gravity, checking that the whole system will work … it is a massive architectural undertaking. It is a massive engineering undertaking. It is a massive social undertaking.

The scale is roughly that of building a new town. The initial location of the new town is rather distant (say, 3AU away), and the techniques of transporting the building materials and the builders are more expensive (the Space Elevator). But the overall image is a good one: we are building a large, multi-person habitation, with every level of service required by an isolated society[111].

We have calculated that we need to lift at least **??6??** million tonnes of matter (see page 99 above) into a 3AU orbit; which , at the cost of $\$1\cdot10^3$ per kilo (achievable using the space elevator) means a transportation cost of $6\cdot10^9 \cdot \$1\cdot10^3 = \$6\cdot10^{12}$. We can estimate the total cost of building and equipping as ten times this, or $\$6\cdot10^{13}$.

Launching

The ship is already in space. Launching means starting the engines and moving away from the Solar System – not a sudden bang and woosh! away, but a more controlled, gentle acceleration, moving further and further away. Even after the engines have started, it may still be possible to chase the ship, and catch up with it, for a while. But eventually the relative velocities will make the ship out of reach.

>>>MORE HERE.

111 A subsequent ship might be larger – the scale, say, of a small city. But that is beyond what we are considering here. **[>>>RECAST FOR 120,000 INITIAL POPULATION <<<]**

Fiscal Impact

We must not skimp. Penny-pinching on a project like this would be ill-advised – and dishonourable. Again we can make a comparison with the construction of cathedrals – the cost did not matter: all that mattered was the quality. If this project turns out to be twice, three times, ten times, a hundred times more expensive than we have envisaged, it does not matter. It is the survival of the human race that is at stake.

As an example of an engineering project that was skimped – though it was extremely costly – consider the development of the Space Shuttle. This was a design that was a compromise between good engineering design and the budget that was allowed. A tiny increase in budget, and the acceptance of a longer delivery time, would have enabled us to produce a truly reusable launch vehicle with a smaller cost per kilogram in orbit. Because we rushed and we skimped we have only a semi-reusable vehicle at a high cost per kilogram in orbit. Now, at the beginning of the 21st century, we are seeing commercial attempts to break in to the satellite market, developing technology that could easily have been developed earlier in time.

>>>>MORE HERE<<<<<

Conclusion

The costs we have estimated as:

Item	**Cost**
Education	$\$4.5 \cdot 10^{11}$
Research	$\$5.0 \cdot 10^{13}$
Development & Design	$\$5.0 \cdot 10^{13}$
Building & Equipping	$\$6.0 \cdot 10^{13}$
Launching	$\$1.0 \cdot 10^{12}$
Total	**»$\$1.6 \cdot 10^{14}$**

This is about one hundred and sixty million million dollars. If this is spread over a hundred years, that is just over a million million dollars per year. That figure divided by just one thousand six hundred million (only a small fraction – less than twenty-five percent – of the world's current population) means a yearly investment of a thousand dollars per year per person in that economically liberated tranche. For one thousand million people the investment is $1,600 dollars per person per year. It is interesting to observe that the most influential tranche – that of education – is also the cheapest (in dollar terms): the leaven in the lump.

The average USA citizen already spends **>>>CHECK THIS>>>** over three times that amount on national defence. If we were to consider the future survival of mankind (the final outcome of interstellar travel) as being as valuable as killing other people (the main outcome of defence) then we could perhaps double our initial budget and consider spending $\$3.0 \cdot 10^{14}$ – or more.

If we look at the 1988 figures quoted by Carl Sagan [Saga1988], we have a world population of 5E9 spending $1E12 or armaments – that is , at 1988 figures, $200 per annum for every man, woman and child upon the planet. At current [2005] values that is equivalent to over $800 for every man, woman and child – including the ones that cannot afford to eat, and the ones that die horrible deaths from poverty, and the ones that have never had any economic influence. $1,600 each for just the wealthy nations is a bargain!

Timescales

Introduction

Let's estimate the timescales to the launch of the first and second ships, with some indication of how long between ships thereafter. Before we start, I have to admit that there is a lot of guesswork here – we cannot really know, only estimate, how long the research and the development are going to take. But we *can* get a feel for the times involved.

We have to look at the following stages:

- Getting the political involvement which moves to a commitment to produce
- Research into propulsion and construction techniques
- Construction of lifting gear, and space habitations
- Construction of initial prototypes to orbit Sol at (say) the distance of Pluto
- Construction and equipping of the first ship
- Launch of the first ship
- Construction and equipping of the second ship
- Journey of the second ship.

Each of these stages has a large degree of uncertainty. Each of these stages involves the spending of money, and of manpower, in getting it completed. We shall consider each stage in turn – together with one extra, and important, remark about punctuality.

Punctuality

In business there is the feeling that punctuality is vital. That, surprisingly, is *not* the correct attitude for the ship. "You can have any two of good price, good quality, good time." For the ship we cannot under any circumstances, compromise quality, even if this means delays in our delivery[112]. We are constructing a ship for thousands of years' service, and delays of four or five years – or even four or five decades – should be accepted. We already know what happens if we allow time, rather than quality, to be our first impetus. In the case of the ship, lack of quality could be fatal.

Let me give two examples – one well-known, the other less so – of engineering projects that were marred by adherence to delivery times: the Met Office building in Exeter, and Terminal 5 at Heathrow Airport.

Met Office

The Met Office in the UK brought together its staff in a single building in Exeter, Devon. This building is a modern, high-tech building intended to be green (of low environmental impact), to provide office space for the central staff (more than a thousand of them), to house the large computer systems required for weather forecasting, and to be an international showplace for British technology. The site chosen was a green field, which was being turned in to an industrial park. The location is near a motorway junction, close enough to the centre of the city to be convenient, and well served by transportation.

But there are at least three big problems with the building, which arose from lack of forethought, and time-pressure during building. I shall call these three problems Water, Walls and Vertigo.

Water

The green field site contained streams; streams contain wildlife, which must be protected, and water, which must be diverted. So these streams were duly diverted. At completion of the project, one of the streams was re-diverted through the new building, serving as a water feature in the central atrium – very impressive (but not

112 Price is discussed elsewhere in this document.

helpful to the wildlife in it).

To make a smaller visual impact the building was set within an artificial hollow, surrounded on several sides by earth banks. The main computer hall is on the lowest floor of the building – very reasonable. The floor of the computer room is a false floor, with a large cable ducting space beneath it – again, very reasonable. But, it would appear, the building was not fully waterproof – very *un*reasonable. During one rainstorm the water from the streams overflowed into the basement of the building, and began to rise in the underfloor space of the computer room, and got to within ten centimetres of the cabling.

Waterproofing has now been improved – partially by digging more drainage channels all around the building – but that waterproofing is something that should have been thought through early on. A building in a depression will naturally be a collecting point for water. Computer halls *do* have to be kept dry.

Walls

As part of the image, it was felt that art should be displayed in the building. But, it turns out, because of time pressures, many of the interior walls – those that are not load-bearing – were of a more flimsy construction than originally designed, and are hence not strong enough to take some of the wall-mounted exhibits desired. The walls are safe – but inferior. So the internal appearance is not as was intended – and lack of art *matters*. Art and elegance make for a more humane environment: ugly or dull surroundings do not of themselves inspire us to actions beyond the ugly and dull.

Vertigo

Some people have vertigo – fear of visible heights. The Met Office building is constructed as a series of independent multi-storey wings, all joined round a spacious central atrium. Some of the paths from one wing to another are across high bridges over that atrium, where the protection is just a handrail balustrade. Vertigo sufferers cannot use these bridges. The alternative route involves taking the lift down to the floor of the atrium, walking across the bottom of the destination wing, and taking the lift back up. But the lifts are placed very close to the ends of the bridges – disturbing – and the fire escape routes are bound to induce panic.

Terminal 5

The politest evaluation of this that I have heard was “fiasco”. There were several problems which were known about during construction, but the warning signs were ignored. It was clear to many of the developers that the building would not be ready, and fit for purpose, on time – but the comments of these developers were turned aside. It was evident, before the building was opened, that (for example) the taxi queuing system was not working. It became (painfully!) evident that the luggage system was not ready, and was not going to be ready. [At the time of writing – April 2008 – it is not yet clear that this system will ever work, or that it will ever work as designed.] The building was tatty and incomplete – only the publicly visible areas were (largely) complete … but tape hung from the ceilings, internal transport systems were not functioning, training was incomplete for access to inadequate computer systems which did the wrong thing at the wrong speed.

The loss of face for BA is not what is important. What is important is that a system was designed, it was constructed, and it did not work. With air traffic baggage systems, we have the opportunity of fixing them, without risk to human life – yes, it’s very annoying, but not vital to humankind. A life support system, however, cannot be debugged on the job – it has to work – and work perfectly – first time of real use.

Cathedrals

Attentive Construction

As a contrast, consider the construction of cathedrals in mediaeval Europe. A cathedral was planned, in full knowledge that its completion would not be in the lifetime of the designers, and that its construction might be delayed over and over again by lack of materials, lack of craftsmen or lack of money. What mattered, at every stage, was that each part was built to the highest standards. [I believe that St. Pauls, in London, was the only major European cathedral built before 1800 that was completed in the lifetime of its architect – in this case, Sir Christopher Wren,] Because for the construction of the cathedral there was time, each item could be designed with care, and considered in its wholeness. The design could be related to the overall architecture of the building, to the historical environment, to ecclesiastical symbolism, and (where relevant) to the engineering and structural needs of the whole building. There was space in which to relate each part to the whole of the structure, without rushing the considerations. The planned life-span of a cathedral was eternity.

>>MORE HERE

Political Involvement

"You may have a different skin colour from me, a different word for God, dance differently, eat differently, speak differently, but we can still live together."

Pete Seager, 2009 <<< CHECK THIS

Problem of Communication

When an scientist uses the word "seven" it means "seven" or "seven, plus or minus the known uncertainty of such-and-such". The engineer does *not* mean "six" or "cost price" or "freedom" or "negotiable, according to the interests of that group of people". When a politician uses the "seven", though, it can mean almost anything.

There are big problems of communication between scientists and politicians. A politician assumes that nearly everything (except his own demands) is negotiable: a scientist knows that nothing is negotiable – Truth is absolute, and we seek to know it better and better. We cannot negotiate the distance to the moon, or adjust the speed of light to be more convenient.

Hence there are certain stern absolutes in the design and construction of the ship. To communicate these at the right level we will need a generation of politicians that are scientifically aware.

As an example of how politics and special interests can make costly interference with engineering design, look at the Space Shuttle. This is a design, and a launching system that is much less refined, much less well-engineered than it could have been, simply because of military insistence. Had the engineers been listened to, we would already have a completely reusable vehicle for space launches: instead, we have a vehicle that is reusable – but with the enormous and costly loss of the carrier at each launch (the fuel tanks and booster rockets). Political language being what it is has then attempted to make the engineers appear responsible for this costly fiasco.

The Interstellar Project (the Interstellar Ship) must not be subject to this kind of misdirection. Avoiding this will be difficult, and will require an effective cultural change.

Time Taken

Of all the stages the hardest is the first – getting the involvement to proceed. To achieve this we have to educate the politicians – which takes at least a generation – or replace the existing politicians (world-wide) with others who are already convinced – which takes at least thirty years[113].

As an illustration, consider the views in the USA and Europe on the use and possession of cannabis. In the 1950s cannabis was not considered a real problem, but was a restricted drug. In the early 1960s the then youth began experimenting with it more and more. The penalties for its possession and sale became larger, and more effort was put into its control. There was, though, a sharp difference of opinion between those under 25 years of age and those over 50 years of age. The older generation – the lawgivers and enforcers – were strongly against allowing cannabis to be available, and the younger generation were strongly for allowing its use. There were marked differences of opinion as to the seriousness of the effects of its use – these opinions were (in a very real sense) religious opinions, rather than based upon scientifically empirical fact.

Now, in the early part of the 21st century, the youth who were smoking then are themselves the lawgivers and enforcers: consequently the penalties have been much reduced, and the classification of cannabis changed, making its possession and use a less serious crime (though still a crime). We still have our – divided – opinions as to the seriousness of its effects, and these opinions are still mostly based upon anecdote and habit, rather than measurement (though some measurement – not necessarily unbiased and independent – has now been made). I anticipate that over the next 50 years numerous countries will remove cannabis from the restricted category, and decriminalise its use and possession, as we come to realise that – empirically – cannabis is less dangerous than alcohol. But note the timescale – fifty years, not five.

Children born after 1980 will have been exposed to computers for

113 Forty or fifty – more than a complete working generation – if you look at the tight cartels controlling the USA and China.

all their lives. Many of them (in Western Europe and America) will have had computer in their own homes for pretty well all of their lives. Hence their attitudes to computers are coloured by their experience – computers are to be expected, they are usual, they are ordinary, what's the big deal? In contrast, to those who were children in the late 1940s and early 1950s the computer is a modern invention. It was a new, complicated, expensive invention that arrived and was used "somewhere else" – outside of the home. It was large, arcane and unusual. It required specialist training, and only the special few could touch it.

Now people from the 1940s/1950s generation are at the top of the decision structures in our society. Very often they do not understand what they are being asked to decide about. The silly[114] attempt by the government of the USA to prevent the use of strong encryption, for example, showed how little the decision makers understood (and perhaps still do not understand) about how scientific information now flows. We are, in many places, repeating with computers the same kinds of laws as required motor vehicles to be escorted by a man carrying a red flag.

It will not be until the 1970s/1980s generation are at the top of the management trees that we will, as a society, be able to make sensible political decisions about the use of computers that are not technically naïve. It takes a generation for big changes to work through.

For the Interstellar Ship we are going to have to wait at least fifty more years to get the new, young generation to the places of power in our society. And for that whole half-century we will have to be persuading, and teaching, and educating, and becoming technically competent – as a society – to start the construction work. Mercifully, the technicians move faster than the politicians.

Levels of Involvement

The design, construction, manning and launching of the Interstellar Ship is so massive a project that the political involvement will have to be at many levels – global, international, national, regional, linguistic, religious, scientific, economic, criminal and commercial.

114 Perhaps we should be more polite and call it "naïve" rather than "silly".

Global

This is a project that affects the whole of mankind. It is a project that must be kept entirely distinct from all sources of conflict. There have been projects in the past that (briefly) lay outside of local identification. Possibly we can consider the internationalization (non-nationalization) of Antarctica, and the general agreement that no part of space should be identified with any one country, nor should space be militarized. Whether these good intentions will actually last into the future, if there is any real prospect of financial advantage or affordable military action is, alas, another question[115].

What do I mean by “Global”? It is from this that all the other levels derive their focus. “Global” means that the whole of mankind is involved, no matter what their location on the planet, no matter what political or religious opinions they hold, no matter when they live – a temporal analogy to “omnipresent, omniscient and eternal”.

When considering the design, creation and support of the ship, one cannot say “this gives nothing to me here”, nor “this gives nothing to me now”, nor “this is too expensive, too slow, too remote”. Well, one *can* say these things, but these are not the direction to look. This is a really long-term project, that affects the survival of the whole of mankind: the longest-term temporal project we have ever undertaken.

>>>more here

International

If just one country, or just one small group of (presumably wealthy) countries were involved in the design and construction, then the project would not be Global. I am not proposing that we insist we have Zulu and Balinese and Guatemalan and Basque (etc.) input controlled in strict ratio of those cultures within mankind, but rather that all cultures and all peoples are of equal value. There is no reason why the design has to be limited to one

115 … and one which realism and historical knowledge obliges one to answer cynically.

place.

For international cooperation at the level we need, we are likely to need an independent, non-aligned body – rather like the United Nations are supposed to be – but one which has no military focus, and cannot be turned to narrow political ends. That body would also have to be one that does not "fudge" and compromise simply for political reasons – only the quality of the engineering counts. Again, think of this project in the same light as the construction of our cathedrals and temples in the past.

We have managed – so far – to keep Antarctica as a neutral territory. It has retained its neutrality partly because it is such a difficult location to use, and partly because we have not yet considered that area's rocks to be economically worth mining. There will have to be development zones on Terra for the ship, and these too should be neutral territories. These will not, though, all be areas as difficult to access and of as poor natural worth (measured in our narrow economics) as Antarctica. At least one of the development areas will be the touch-down site for a Space Elevator. This will have to be on (or very near) the Equator – and all of those areas are currently of relatively high economic worth.

Part of our international agreement, though, will have to recognize the utter neutrality of such areas.

<<<MORE here

>>more here: co-operation between countries required; avoidance of local dictatorships; this is at a higher level than the United Nations; even warring countries can co-operate; discuss location of space elevator or space elevators; discuss national neutrality of the development zone(s);>>>

National

"Patriotism is loving one's country: nationalism is hating all others." [<<<CHECK attribution and date>>>]

It is lamentable, that to be a good patriot one must become the enemy of the rest of mankind. ~Voltaire, *Philosophical Dictionary*

Patriotism is when love of your own people comes first;

nationalism, when hate for people other than your own comes first. ~Charles de Gaulle

Nationalism is a silly cock crowing on his own dunghill. ~Richard Aldington

I am not an Athenian or a Greek, I am a citizen of the world. ~Socrates

You'll never have a quiet world till you knock the patriotism out of the human race. ~George Bernard Shaw

Nationalism is an infantile disease. It is the measles of mankind. ~Albert Einstein, *The World As I See It*, 1934

To him in whom love dwells, the whole world is but one family. ~Buddha

To me, it seems a dreadful indignity to have a soul controlled by geography. ~George Santayana

The love of one's country is a splendid thing. But why should love stop at the border? ~Pablo Casals

No nation is to be preferred above any other. Indeed, by the time the ship is launched (or even during the earlier time of construction) we may have at last lost our recent madness for preferring one group of people over all others.

>>more here: no nation to be preferred above any other; this is not a USA or a Chinese or a European (etc.) project; avoidance of nationalistic fervour and dictatorships;<<

Regional

>>more here: no specific region to be preferred above any other;<<

Global, international, national, regional – ultimately the focus is personal. There is no person who could potentially contribute that is to be preferred above any other.

<<<MORE HERE

Linguistic

We have to consider the language(s) that will be used on the ship, and the language(s) used in designing the ship. These are separate, but related, issues. The on-ship languages are discussed at [REF], and the design-time languages are discussed here.

There is long discussion about whether the language forms the thought, or the thought forms the language. Whichever view you take[116], it is certain that language influences the available reference material. There is very little written about philosophy in Danish, for example, which is one reason why Kierkegaard[117] [CHECK] was unknown for decades, until his work was translated in to German. For the Ship's design, we do not want the designers to be *ab initio* cut off from all other influences, and we do not want the designers' writings to become an un-openable, closed book.

There are some very narrow linguistic (or quasi-linguistic) considerations that can be decided immediately, and without much conflict – that the metric system should be used throughout, for example, and that time should be measured in Astronomical (or Julian) days – but the broader considerations of the difficulty of translating formal designs between, say, French, English and Swahili are what we are looking at here.

The design and construction will be done worldwide, and there must be no particular bias to any one linguistic group over any other. The largest groups (in having the largest numbers of speakers) should, for practical reasons, be represented in all the formal documents, but we may discover that we have to focus on a Ship's Language long before its departure, and use that as the lingua franca.

Elsewhere [REF] it is pointed out that the final Ship's Language (the language that will be spoken onboard the ship) is likely to be a mixture of English, Spanish, Mandarin Chinese, Hindi/Urdu and Arabic/Hebrew – with French, Urdu and Russian influences as

116 The Sapir/Worf Hypothesis has generated much heat, and perhaps a little light. See [REF] <<<INSERT REFERENCE HERE

117 Søren Aabye Kierkegaard, 1813-1855, Danish philosopher and theologian. See http://en.wikipedia.org/wiki/Søren_Kierkegaard

well. For non-formal use, a language can be created in a single generation. For formal use there has to be some history – but not much – and a means of relating the new language to other, more established and older languages. The definition of “ShipSpeak” is very like the definition of (say) Esperanto[118], and that was created in a single man’s lifetime, and now after 120 years (or thereabouts) has native speakers and body of both translated and original literature. The more recent artificial language Lojban explicitly draws from Arabic, Chinese, English, Hindi, Russian, Spanish – and Formal Logic, though it does not have as many fluent speakers (if any).<<<MORE HERE

[The amalgam language is very likely to be a mixture of English, Spanish, Mandarin Chinese, Hindi and Arabic – with French, Urdu and Russian influences as well.]

>>more here: language on the ship discussed elsewhere; language used by the design and development team; non-specificity of language required

Religious

Man is a religious animal. *Which* religion, though, is as variable as hair colour and music. Man is a political animal too, and there is a mixture between the political impulse and the religious impulse. We speak of Churches, schools of Islam, religious organizations, the state religion – all names for organized groups of people rather than modes of thought.

Because the religious groups wield such power, it is essential that the construction of the ship is accepted by the large majority of them. More precisely, because the ship is such a large venture, it must be accepted by a large majority of mankind: if any religious organization declares itself against the design and construction of the ship, and that organization influences a large number of people, then we have a problem.

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118 First defined in *Unua Libro* by Dr. Ludovic Lazarus Zamenhof in 1887 [Zame1887]. This is a language based on Russian, German, Polish French and English – with Greek, Latin, Italian, Spanish, Portuguese and other influences too.

How we address each large grouping has to be considered separately for each religion, and in some cases for each sect: what will persuade the Bahai may not influence the followers of Zen or Shinto.

This is different from the religion(s) actually onboard the ship – that is discussed at [REF] – what is being discussed here are the religions on Terra, and the organizations that may influence attitudes towards the design and construction of the ship.

>>more here: acceptance by major religious organizations required;

Scientific

>>more here: scientific research possibilities; technological development encouraged; best scientific input required in design and development

Economic

>>big effect upon local and global economy

Criminal

Large projects turn over large quantities of resources. There is inevitable criminal temptation here, and we cannot avoid criminal activity.

>>more here

Commercial

>>more here

Research

We have already developed nearly enough – but not quite enough – to build the interstellar ship. Amongst what we need to develop are:

- Stronger materials, for constructing the space elevator;
- Good methods of applying massive propulsive forces to extremely large objects;
- Stable artificial biomes;
- Testing methodologies for extremely long projects (projects with expected life-spans of millennia);
- Power generation methods – the one area in which I have personal doubts: if we cannot harness controlled nuclear fusion (or something else as energy-generous) then we cannot begin;
- Power transmission methods.

Transportation

We have mentioned the Space Elevator, and we have mentioned the moving of the ship by simple rocket propulsion. We have to look at the development of these two technologies, to ensure that we have effective techniques.

Rocket Propulsion

From the nature and size of the ship, ordinary chemical rocket propulsion is out of the question. The method of moving the ship is still likely to be dependent upon action/reaction, but energised by something other than a chemical reaction. The size of particles emitted (the ejecta) does not have to be very large.

>>more here

Space Elevator

The space elevator …

Force transmission

>>more here

Artificial Biomes

>>more here

Power Generation

>>more here

Power Transmission

If we consider electrical power, its transmission is along cables. We normally, on Earth, make those cables insulated and put them underground, or leave them un-insulated, and hang them from pylons. At present it appears that to impart energy to the pods on the Space Elevator we are going to have to develop a non-cable means of transferring power – laser radiation is being considered, and perhaps ultra-short wave radio transmission could also be used.

Within the ship the power can possibly be transmitted by insulated cables – but we will have to remember that cables wear out and need replacement, so they must be accessible, even if hidden. There are some parts of the power, however, that are quite difficult to choose good transmission media for – the internal energy radiation keeping the light and heat levels up, for example (the ‘quasi-Sun’), and the transmission of energy to the propulsion system (which may not have a fixed internal location).

Prototypes

This is a long project. We would be advised to build a prototype and try it out, without leaving the Solar System, before constructing the first real long-distance ship. The prototype could be a “small” asteroid (say, under 20 km in diameter), which is put into a long orbit at about the distance of Neptune or Pluto. This would allow us to test the habitation mechanics on a small scale for a period of a few decades, before committing ourselves to particular technical choices for the big ship. We could perhaps use the prototype as a staging station for construction of the big ship, and we could certainly use the prototype as the base for effective astronomical research.

Construction of Trial Ship

The first ship, the trial ship, will take decades to build. Exactly how long, we cannot yet say with certainty. I would suggest that it will take at least 50 year to construct, possibly 100 years. The initial design stage will itself be considerable – more massive than any other design undertaken. The construction is (inevitably) of the largest single machine we have ever built.

Part of the building involves the setting up of the social structures that can sustain and run such a ship. There will have to be "drivers" and "engineers" for the ship. I place these in quote marks, because "driving" an interstellar ship is a different sort of driving than we have undertaken before. Consider a bicycle, now consider driving a car, now consider driving an oil-tanker … each of these has acceleration and turning characteristics completely different from the others. The interstellar ship will be far beyond the oil-tanker in its inertial solidity, and far more difficult to get moving (and to stop) than any earth-bound vehicle. And it is also not really like driving a rocket – at least, not the rockets we have already experienced (such as got us into orbit, and to the moon).

Launch of Trial Ship

So we have done the research, we have undertaken the massive design effort, we have spent perhaps a century in expensive and labour-intensive construction of the ship, we have decided in what direction it is going to be launched, we have chosen the initial inhabitants of the ship – the ancestors of our descendants – and we are ready to go.

Because of the mass of the ship, its initial acceleration will appear to be minimal. It will take it a long time to leave the solar system – perhaps several decades – but all the time the ship will be picking up speed, moving away from Earth (Terra) faster and faster. We will be communicating with the ship. The communication will, at first, be relatively easy, but become more and more difficult. When the distance increases it will be impossible to have real conversation, and each side will be issuing effective monologues – answering points made (perhaps) weeks or months before by the other side. Eventually the communication will be beyond our capability – so tenuous as to be impossible to receive, and so distant that the turn-round time for a message will make simulated conversation ridiculous or impossible.

Then she is on her own.

Construction of the Real Ship

Well, we have built one, and learnt from it. Why not build another, the real one? Remember – a single ship can be destroyed with a single disaster – but a fleet of ships greatly increases the probability of some ship surviving.

And the second ship could be – after we have learnt from the first ship – much larger. Perhaps this time we could consider initially sending 250,000 or 500,000 people – equivalent to a small city[119] of people.

Or should we consider something very much larger indeed?

Maybe we already have the second ship available, with room for a very large number of travellers – thousands of millions of them. And that ship is travelling at a fair old lick – it makes one circuit round the Milky Way galaxy in less than three hundred million years, and it has a ready-made, stable biome which has lasted longer than a thousand million years. It contains all the right elements, in the right proportions, for the sustenance of human life, and has a free supply of exactly the right amount of energy to maintain its average temperature at 288 K°. – exactly right for us.

And that's Terra – The Earth upon which we all live.

A single ship can be destroyed with a single disaster, and this Earth ship too (just like the artificial interstellar ship we have been discussing) will be destroyed at some time – inevitably. We can bring that time of destruction near to us by being greedy and stupid. We already have the technological means of destroying all human life on Earth, and research now being done will give us the ability to destroy absolutely all life on Earth – human, animal, insect, plant, microbe – the lot. We can push the time of destruction away from us only by being attentive, and caring for our planet. We must not poison it, we must not overheat it, we must not scar it, we must not kill its inhabitants. Let me rewrite that sentence: we must not *continue to* poison it, we must not *continue to* overheat it,

119 This would be like, say, transporting the whole of Exeter or Bristol into space. And a lovely thing that would be, too! And I do *not* mean "hooray, we are getting rid of Exeter" but the reverse: "Here is Exeter – a superb collection of mankind."

we must not *continue* scarring and destroying it, we must not *carry on* killing in their millions other men, and annihilating irreplaceable species of living beings.

Launch of Second Ship

The second ship has already been launched: we are on it. And this ship is going to a different destination from any we imagined for our artificial ship. That destination is the future.

We can, if we try, pull back from the disaster that will destroy us all within four hundred years. We must all of us – the whole of humankind – practise good husbandry, looking after our planet as we would a treasured garden. We must all of us – the whole of humankind – accept the limitations of energy use and modification to the natural biome which that husbandry requires. And we must all of us accept the more simple, balanced lifestyles that can be supported using only the naturally received energy, at the rate it is received, without calling upon the geologically stored banks of energy[120], or upon nuclear power – the use of these ultimately warms the planet and de-stablalises the biome.

We can, if we try, save The Earth.

It will be hard work – but worth it. Without undertaking it, mankind is doomed. To survive, we have to make the effort.

Per Ardua ad Astra.

ץראה תאו ,םיימשה תא ,םיהולא ארב ,תישארב.

120 Fossil fuels and artificially-released volcanic heat.

Tables

This section contains some reference tables that are background to the text, but do not have to be read with it.

Sizes and Distances

Astronomical Unit, mean distance Earth-Sun 1 AU = $1.49597870691 \cdot 10^{11}$ m ≈ 1.5 E11 m

Speed of light *c* = 299,792,458 m/s ≈ 3 E8 m/s

1 year = 365.25 days = 31557600 s ≈ p E7

Parsec, lightyear , AU: 0.306607 pc = 1 ly = 63242.18 AU = $9.460896 \cdot 10^{15}$ m ≈ 9.5 E15 m

Parsec: 1 pc = 3.26163626 ly = $3.08568025 \cdot 10^{16}$ m ≈ 3.1 E16 m

Radius of the Earth (Terra) $R_E = 6.378136 \cdot 10^{6}$ m ≈ 6.4 E6 m

Mass of the Earth (Terra) $M_E = 5.9742 \cdot 10^{24}$ kg ≈ 6 E24 kg

Radius of the Sun (Sol) R□ = $6.378136 \cdot 10^{6}$ m ≈ 6.4 E6 m FIX

Mass of the Sun (Sol) M□ = $1.98892 \cdot 10^{30}$ kg ≈ 2 E30 kg

Elements

Element	Atomic No. / Sign	Organic	Air & Air Stock	Water (Fresh & Salt)	E [121]	L [122]
Hydrogen	1 H	1.81E+7	1.0E+6	1.10E+8	P	P
Helium	2 He				P	
Lithium	3 Li			1.7E+2	P	P
Beryllium	4 Be				P	
Boron	5 B			4.5E+3	P	
Carbon	6 C	1.8E+7	3.2E+6	2.8E+4	P	P
Nitrogen	7 N	3.0E+6	7.8E+8	1.5E+4	P	P
Oxygen	8 O	5.1E+8	2.1E+8	8.83E+8	P	P
Fluorine	9 F			1.3E+4	P	P
Neon	10 Ne		1.8E+5	8.8E+1	P	
Sodium	11 Na	2.35E+7		1.08E+7	P	P
Magnesium	12 Mg	1.72E+7		1.29E+6	P	P
Aluminium	13 Al	6.75E+7		4.5E+3	P	?
Silicon	14 Si	2.3E+8		2.9E+3	P	P
Phosphorus[123]	15 P	1.2E+6		1.0	P	P
Sulphur	16 S			9.0E+5	P	P
Chlorine	17 Cl	1.9E+6		1.94E+7	P	P
Argon	18 Ar		1E+7	1.9	P	
Potassium	19 K	2.16E+7		3.9E+5	P	P
Calcium	20 Ca	3.25E+7		4.1E+5	P	P
Scandium	21 Sc			2.0E-1	?	
Titanium	22 Ti	5.5E+6			P	
Vanadium	23 V				?	
Chromium	24 Cr				P	?

121 Engineering

122 Life

123 ??? This quantity is *far* too small!!! <<<RECALCULATE

Manganese	25 Mn			4.0E-1	P	P
Iron	26 Fe	4.23E+7		3.4	P	P
Cobalt	27 Co			3.9E-1	P	?
Nickel	28 Ni			6.6	P	
Copper	29 Cu				P	P
Zinc	30 Zn				P	P
Gallium	31 Ga				P	
Germanium	32 Ge				P	
Arsenic	33 As				P	?
Selenium	34 Se				P	?
Bromine	35 Br			6.7E+4	P	P
Krypton	36 Kr				P	
Rubidium	37 Rb				?	
Strontium	38 Sr				P	?
Yttrium	39 Y				?	
Zirconium	40 Zr				P	
Niobium	41 Nb				?	
Molybdenum	42 Mo				P	
Technetium	43 Tc				?	
Ruthenium	44 Ru				?	
Rhodium	45 Rh				?	
Palladium	46 Pd				P	
Silver	47 Ag				P	?
Cadmium	48 Cd				?	
Indium	49 In				?	
Tin	50 Sn				P	P
Antinomy	51 Sb				?	
Tellurium	52 Te				P	
Iodine	53 I				P	P
Xenon	54 Xe				P	
Caesium	55 Cs				P	?

Barium	56 Ba				P	?
Lanthanum	57 La				P	
Cerium	58 Ce					
Praseody-mium	59 Pr					
Neodymium	60 Nd					
Promethium	61 Pm	0	0	0		
Samarium	62 Sm					
Europium	63 Eu					
Gadolinium	64 Gd					
Terbium	65 Tb					
Dysprosium	66 Dy					
Hafnium	67 Ho					
Erbium	68 Er					
Thulium	69 Tm					
Ytterbium	70 Yb					
Lutetium	71 Lu					
Haffnium	72 Hf					
Tantalum	73 Ta				P	
Tungsten	74 W				P	
Rhenium	75 Re					
Osmium	76 Os				?	
Iridium	77 Ir				P	
Platinum	78 Pt				P	
Gold	79 Au				P	?
Mercury	80 Hg				P	?
Thallium	81 Tl				P	
Lead	82 Pb				P	?
Bismuth	83 Bi				P	?
Polonium	84 Po					
Astatine	85 At	0	0	0	0	0
Radon	86 Rn	0	0	0	P	0

Francium	87 Fr	0	0	0	0	0
Radium	88 Ra	0	0	0	P	0
Actinium	89 Ac	0	0	0	0	0
Thorium	90 Th				?	
Protactinium	91 Pa					
Uranium	92 U				P	
Neptunium	93 Np					
Plutonium	94 Pu				?	
Americium	95 Am	0	0	0	0	0
Curium	96 Cm	0	0	0	0	0
Berkelium	97 Bk	0	0	0		
Californium	98 Cf	0	0	0		
Einsteinium	99 Es	0	0	0		
Fermium	100 Fm	0	0	0		
Mendelevium	101 Md	0	0	0		
Nobelium	102 No	0	0	0		
Lawrencium	103 Lr	0	0	0		
Rutherfordium	104 Rf	0	0	0		
Dubnium	105 Db	0	0	0		
Seaborgium[124]	106 Sg	0	0	0		
Bohrium	107 Bh	0	0	0		
Hassium	108 Hs	0	0	0		
Meitnerium	109 Mt	0	0	0		
Darmstadtium	110 Ds	0	0	0		

124 The only element named after a then *living* chemist, Nobel Lauriat **Glenn Theodore Seaborg**, 19 April 1912 – 25 February 1999. He was a key member of the teams that discovered (or verified) ten new elements, including: americium (95) and curium (96) [for which two elements he held – extraordinarily – patents!], berkelium (97), californium (98), einsteinium (99), fermium (100), mendelevium (101), and nobelium (102) [Seab2005].

Roentgenium	111 Rg	0	0	0		
Totals						

Use of Elements

Element	Use
Hydrogen	(Basic)
Helium	Basic to the universe – engineering (inert gas)
Lithium	Ceraics, metal alloys, drugs, electronics
Beryllium	Alloys, nuclear energy uses, very poisonous – many uses
Boron	Electronics, semiconductors, medical, materials, etc.
Carbon	(Basic)
Nitrogen	(Basic)
Oxygen	(Basic)
Fluorine	
Neon	
Sodium	(Basic)
Magnesium	(Basic)
Aluminium	
Silicon	(Basic)
Phosphorus	(Basic)
Sulphur	(Basic)
Chlorine	(Basic)
Argon	
Potassium	(Basic)
Calcium	(Basic)
Scandium	
Titanium	
Vanadium	
Chromium	
Manganese	
Iron	(Basic)
Cobalt	
Nickel	

Copper
Zinc
Gallium
Germanium
Arsenic
Selenium
Bromine
Krypton
Rubidium
Strontium
Yttrium
Zirconium
Niobium
Molybdenum
Technetium
Ruthenium
Rhodium
Palladium
Silver
Cadmium
Indium
Tin
Antinomy
Tellurium
Iodine
Xenon
Caesium
Barium
Lanthanum
Cerium
Praseodymium
Neodymium

Promethium	
Samarium	
Europium	
Gadolinium	
Terbium	
Dysprosium	
Hafnium	
Erbium	
Thulium	
Ytterbium	
Lutetium	
Haffnium	
Tantalum	
Tungsten	
Rhenium	
Osmium	
Iridium	
Platinum	Engineering and decorative uses
Gold	Many engineering – and cosmetic (decorative) – uses
Mercury	Many engineering uses
Thallium	Used in medicine, glass manufacture, electronics and poisons
Lead	Many engineering uses
Bismuth	Metal alloys, nuclear energy, medical and cosmetic compounds
Polonium	Energy source, radiation source – but *extremely* dangerous
Astatine	---
Radon	Cancer treatment, inert gas
Francium	---
Radium	(Possible radiation source)
Actinium	Valuable neutron (radiation) source

Thorium	Nuclear energy, metal alloys, welding
Protactinium	---
Uranium	Nuclear energy, glass colouring
Neptunium	(Possible radiation source)
Plutonium	Waste product from production of fission energy, but also an energy source itself.
Americium	Efficient radiation source
Curium	(Possible energy source)
Berkelium	---
Californium	---
Einsteinium	---
Fermium	---
Mendelevium	---
Nobelium	---
Lawrencium	---
Rutherfordium	---
Dubnium	---
Seaborgium	---
Bohrium	---
Hassium	---
Meitnerium	---
Darmstadtium	---
Roentgenium	---

Asteroids

Asteroids are divided into classes. C = Carbonaceous, S = Silicacious, M = Metalic were the first classes – but now there are other, subordinate forms.

Tholen classification:

C-group dark carbonaceous objects, including several sub-types: B-type, F-type G-type, C-type the remaining majority of 'standard' C-type asteroids. This group contains about 75% of asteroids in general.)
S-type silicaceous (*i.e.* stony) objects. This class contains about 17% of asteroids in general.
X-group: **M-type** metallic objects, the third most populous group, E-type differ from M-type mostly by high albedo, P-type differ from M-type mostly by low albedo
A-type a small category
D-type a small category
T-type a small category
Q-type for (1862) Apollo
R-type for (349) Dembowska
V-type for (4) Vesta

SMASS forms:
C-group of carbonaceous objects including: B-type largely overlapping with the Tholen B and F types, C-type the most 'standard' of the non-B carbonaceous objects, Cg Ch Cgh somewhat related to the Tholen G type, Cb transition objects between plain C and B types.

S-group of silicaceous (stony) objects including: A-type, Q-type, R-type, K-type (a new category), L-type (a new category), S-type (the most 'standard' of the S group), Sa, Sq, Sr, Sk, and Sl transition objects between plain S and the other types in the group.
X-group of mostly metallic objects including: X-type the most 'standard' of the X group including objects classified by Tholen as M, E, or P-type, Xe, Xc, and Xk transition types between plain X and the appropriately lettered types.
T-type
D-type
Ld-type: a new type with more extreme spectral features than the

L-type
O-type
V-type

It is the SMASS classes that are used here.

Asteroid Name & No., or Moon Name	Sizes (diameters in km.)	Mass (kg.)	Distance (in AU) from Sol	Density g/cm^3, Class
4581 Asclepius	0.3	(2.67E+10, 3.53E+10)	1.02	
6489 Golveka	0.35 x 0.25 x 0.25	(1.83E+10, 2.86E+10)		Q
1915 Quetalcoatl	0.4	(5.36E+10, 8.37E+10)		SMU
3757 1982 XB	0.4	(5.36E+10, 8.37E+10)		S
1992 UY4	1.1	(8.36E+11, 1.12E+12)	2.65	(1.2)
1994 CC	1.1	(8.36E+11, 1.12E+12)	1.63	(1.2)
1999 AN10	1.1	(8.36E+11, 1.12E+12)	1.46	(1.2)
2000 DP107	1.1	(8.36E+11, 1.12E+12)	1.36	(1.2)
1994 PM	1.2	(1.08E+12, 1.45E+12)	1.47	(1.2)
1998 WT24	1.2	(1.08E+12, 1.45E+12)	0.71	(1.2)
1566 Icarus	1.3	(1.84E+12, 2.87E+12) [**1.0**E+**12**]	1.07	SU,Q
1862 Apollo	1.4	(2.29E+12, 3.59E+12) [**2.0**E+**12**]	1.47	Q, S
7482 1994 PC1	1.4 (?1.9?)	(2.29E+12, 3.59E+12)	1.34	S
4450 Pan	1.57	(3.24E+12, 5.06E+12)	1.44	

Asteroid Name & No., or Moon Name	**Sizes (diameters in km.)**	**Mass (kg.)**	**Distance (in AU) from Sol**	**Density g/cm³, Class**
1997 XF11	1.9	(4.31E+12, 8.98E+12)	1.44	(1.2)
1999 KW4	2.0	(5.02E+12, 6.70E+12)	0.64	(1.2)
2002 NT7	2.0	(5.02E+12, 6.70E+12)	1.73	(1.2)
3554 *Amun*	2.1	(7.75E+12, 1.21E+13)		M (1.6)
9969 Braille	2.2 x 1.0	(1.84E+12, 2.88E+12)	2.34	O
1986 DA	2.3	(1.01E+13, 1.59E+13)	2.81	M (1.6)
3352 McAuliffe	2.4 (?2 to 5?)	(1.15E+13, 1.81E+13)	1.87	S
3103 Eger	2.5? 1.5?	(1.30E+13, 2.05E+13)	1.40	E
4486 Mithra	3.0	(2.26E+13, 3.53E+13)	2.2	
1864 *Daedalus*	3.1	(2.49E+13, 3.90E+13)		Sr
3753 *Cruithne*	5	(3.01E+13, 4.70E+13)	0.997 to Sol or 0.3 from Terra	Q
5535 AnneFrank	4.0	(5.36E+13, 8.37E+13)	2.21	
4179 Toutatis	4.6 x 2.4 x 1.9	(2.08E+13, 2.30E+13) [**5.0**E+**13**]	2.51	S,Sq [2.1]
1620 Geographos	5 x 2 x 1	(8.37E+13, 1.30E+14) [**4.0**E+**12**]	1.24	S
3200 Phaethon	5.1	(1.11E+14, 1.73E+14)	1.27	B,F
4979 Otawara	5.5	(1.39E+14,	2.16	

Asteroid Name & No., or Moon Name	Sizes (diameters in km.)	Mass (kg.)	Distance (in AU) from Sol	Density g/cm³, Class
		2.17E+14) [**2.0**E+**14**]		
Trinculo	10	(8.37E+14, 1.30E+15)		
Leda	16	5.68E+15		
M1 Phobos	19 x 21 x 27	(1.09E+16, 1.12E+16)		1.95 (S?)
951 **Gaspra**	19 x 12 x 11	(2.10E+16, 2.36E+16) [**1.0**E+**16**]	2.20	S (1.6)
Adrastea	20 (23 x 20 x 15)	1.91E+16		
Pan	20	(6.70E+15, 1.04E+16)		
Cordelia	26	(1.47E+16, 2.30E+16)		
Calypso	26 (34 x 22 x 22)	(1.37E+16, 2.15E+16)		
Telesto	29 (34 x 28 x 36)	(2.87E+16, 4.86E+16)		
Atlas	30 (40 x 20)	(1.34E+16, 2.09E+16)		
Stephano	30	(2.26E+16, 3.53E+16)		
Ananke	30	3.82E+16		
Ophelia	32	(2.74E+16, 4.28E+16)		
847 Agnia	32	(2.74E+16, 4.28E+16)	2.78	S (1.6)
863 Benkoela	32	(2.05E+16, 2.74E+16)	3.20	A (1.2)
Helene	33 (36 x 32 x 30)	(2.89E+16, 4.52E+16)		
1998 SG35	35	(2.69E+16, 3.59E+16)		(1.2)

Asteroid Name & No., or Moon Name	**Sizes (diameters in km.)**	**Mass (kg.)**	**Distance (in AU) from Sol**	**Density g/cm³, Class**
Lysithea	36	7.77E+16		
Sinope	36	7.77E+16		
1036 Ganymed	38.5? 41?	(5.09E+16, 5.72E+16)	2.66	S (1.6)
433 **Eros**	39 x 13 x 13	(8.28E+16, 9.21E+16) [**6.69**E+**15**]	1.45	2.67 [2.4] S
Setebos	40	(5.36E+16, 8,37E+16)		
Carme	40	9.56E+16		
Metis	40 (40 x 60)	9.56E+16		
446 Aeternitas	43	(4.99E+16, 6.61E+16)	2.78	A (1.2)
Bianca	44	(7.13E+16, 1.11E+17)		
113 Amalthea	48	(9.26E+16, 1.04E+17)	2.37	S (1.6)
243 **Ida**	48 x 24	(3.61E+16, 3.90E+16) [**1.0**E+**17**]	2.86	2.7 [2.5] (S?)
Prospero	50	(1.04E+17, 1.63E+17)		
Pasiphae	50	1.91E+17		
Rosalind	54	(1.31E+17, 2.06E+17)		
584 Semiramis	56	(1.37E+17, 1.47E+17)	2.37	S (1.6)
Desdemona	58	(1.63E+17, 2.55E+17)		
Caliban	60	(1.81E+17, 2.82E+17)		
67 Asia	60	(1.81E+17, 2.82E+17)	2.42	S (1.6)
82 Alkmene	64	(2.19E+17,	2.76	S (1.6)

Asteroid Name & No., or Moon Name	Sizes (diameters in km.)	Mass (kg.)	Distance (in AU) from Sol	Density g/cm^3, Class
		3.43E+17)		
43 Ariadne	65	(2.30E+17, 3.59E+17)	2.20	S (1.6)
Cressida	66	(2.40E+17, 3.76E+17)		
253 Mathilde	66 x 48 x 46	(9.19E+16, 1.06E+17) [**1.033**E+**17**]	2.64	1.3 C (1.4)
Belinda	68	(2.64E+17, 4.11E+17)		
44 Nysa	73	(2.44E+17, 3.25E+17)	2.42	E (1.2)
Elara	76	7.77E+17		
25 Phocaea	78	(3.97E+17, 6.46E+17)	2.40	S (1.6)
80 Sappho	82	(4.61E+17, 7.21E+17)	2.29	S (1.6)
Juliet	84	(4.95E+17, 7.75E+17)		
115 Thyra	84	(4.95E+17, 7.75E+17)	2.38	S (1.6)
Pandora	84 (114 x 84 x 62)	2.20E+17		
Prometheus	91 (145 x 85 x 62)	2.70E+17		
17 Thetis	93	(6.73E+17, 1.05E+18)	2.46	S (1.6)
26 Proserpina	99	(8.12E+17, 1.27E+18)	2.65	S (1.6)
Thebe	100 (100 x 90)	7.77E+17		
674 Rachele	101	(8.63E+17, 9.71E+17)	2.92	S (1.6)
140 Siwa	103	(6.86E+17, 9.15E+17) [**1.5E+18**]	2.73	C (1.2)

Asteroid Name & No., or Moon Name	Sizes (diameters in km.)	Mass (kg.)	Distance (in AU) from Sol	Density g/cm³, Class
387 Aquitania	106	(9.97E+17, 1.55E+18)	2.74	S (1.6)
42 Isis	107	(1.02E+18, 1.60E+18)	2.44	S (1.6)
63 Ausonia	108	(1.05E+18, 1.64E+18)	2.39	S (1.6)
Portia	110	(1.11E+18, 1.74E+18)		
40 Harmonia	111	(1.14E+18, 1.28E+18)	2.26	S (1.6)
37 Fides	112	(1.17E+18, 1.32E+18)	2.64	S (1.6)
Epimetheus	115 (114 x 108 x 98)	5.59E+17		
Phoebe	115 x 110 x 115	4.00E+18		2.3
588 Achilles	116	(1.30E+18, 2.04E+18)		D (Lagran-gian L4)
12 Victoria	117	(1.34E+18, 1.51E+18)	2.33	S (1.6)
Sycorax	120	(1.44E+18, 2.26E+18)		
68 Leto	127	(1.71E+18, 1.93E+18)	2.78	S (1.6)
349 Dembowska	140	(1.72E+18, 2.30E+18)	2.92	R (1.2)
8 Flora	141	(2.34E+18, 2.64E+18)	2.20	S (1.6)
18 Melpemone	148	(2.71E+18, 3.05E+18)	2.29	S (1.6)
20 Massalia	151	(4.68E+18, 5.04E+18)	2.40	2.7, S
Puck	154	(3.06E+18, 4.78E+18)		

Asteroid Name & No., or Moon Name	**Sizes (diameters in km.)**	**Mass (kg.)**	**Distance (in AU) from Sol**	**Density g/cm^3, Class**
39 Laetitia	159	(3.36E+18, 3.78E+18)	2.76	S (1.6)
11 Parthenope	162	(3.56E+18, 4.01E+18)	2.45	S (1.6)
354 Eleonora	162	(3.56E+18, 4.01E+18)	2.79	S (1.6)
9 Metis	168 x 210	(4.96E+18, 5.58E+18)	2.36	S (1.6)
Janus	178 (196 x 192 x 150)	1.98E+18		
2060 Chiron	180 x 148	(3.30E+18, 3.71E+18) [**4.0E+18**]	13.63	B
6 Hebe	185	(5.30E+18, 5.96E+18)	2.42	S (1.6)
Himalia	186	9.56E+18		
Amalthea	189 (270 x 166 x 150)	3.5E+18		
7 Iris	203	(7.00E+18, 7.88E+18)	2.38	S (1.6)
215 **Kleopatra**	217 x 94 x 81	(1.34E+18, 2.16E+18)	2.76	M
Phoebe	220	4.00E+18		2.3
45 Eugenia	226	(7.25E+18, 9.67E+18) [**6.1E+18**]	2.721	1.2 FC
24 Themis	228	(9.93E+18, 1.55E+19)	[3.134]	
95 Arethusa	230	(1.01E+19, 1.59E+19)	3.07	
532 Herculina	231	(1.03E+19, 1.16E+19)	2.77	S (1.6)
3 Juno	244	(1.21E+19, 1.36E+19) [**2.0E+19**]	2.67	(1.6) S

Asteroid Name & No., or Moon Name	**Sizes (diameters in km.)**	**Mass (kg.)**	**Distance (in AU) from Sol**	**Density g/cm^3, Class**
324 Bamberga	246	(1.24E+19, 1.94E+19)	2.68	
48 Doris	250	(1.30E+19, 2.04E+19)	3.10	
92 Undina	250	(1.30E+19, 2.04E+19)	3.18	
16 Psyche	264	(1.54E+19, 1.73E+19)	2.92 [2.619]	1.6 [1.8], M
15 Eunomia	272	(1.68E+19, 1.89E+19)	2.64	S (1.6)
451 Patienta	276	(1.76E+19, 2.75E+19)	3.06	
Hyperion	286 (410 x 260 x 220)	1.77E+19		1.1
52 Europa	289	(2.02E+19, 3.16E+19)	2.72 [3.099]	FC
624 Hektor	300 x 150	(4.24E+18, 5.65E+18)		D (1.2)
65 Cybele	309	(2.47E+19, 3.86E+19)	3.5	
511 Davida	323	(2.82E+19, 4.41E+19)	3.17	
704 Interamnia	350	(3.59E+19, 5.61E+19)	3.06	
31 Euphrosyne	370	(4.42E+19, 6.63E+19)	3.14	
Mimas	392	3.75E+19		
10 Hygiea	450	(7.63E+19, 1.19E+20)	3.13	
Miranda	472	6.59E+19		
Enceladus	498	7.30E+19		
4 Vesta	570 x 460	(2.08E+20, 2.21E+20) [**3.0**E+**20**]	2.36	3.5 [4.3] [3.3] V (U)

Asteroid Name & No., or Moon Name	**Sizes (diameters in km.)**	**Mass (kg.)**	**Distance (in AU) from Sol**	**Density g/cm^3, Class**
2 Pallas	570 x 525 x 482	(2.11E+20, 2.41E+20) [**3.18**E+**20**]	2.77	2.8 [4.2] [3.2] U
1 Ceres	960 x 932	(8.97E+20, 1.17E+21) [**8.7**E+**20**]	2.76	2.05 [2.7] C
Tethys	1060	6.22E+20		
Dione	1120	1.05E+21		
Ariel	1158	1.35E+21		
Umbriel	1170	1.17E+21		
Quaoar	1280	(1.75E+21, 2.74E+21)	43.37	
Iapetus	1460	1.59E+21		1.27
Oberon	1523	3.01E+21		
Rhea	1530	2.31E+21		
Titania	1578	3.53E+21		
Europa	3138	4.80E+22		
Io	3632	8.93E+22		
Callisto	4820	1.08E+23		
Titan	5150	1.35E+23		1.88
Ganymede	5262	1.48E+23		

Population Densities

Radius km	Area km^2	Popln. at $14/km^2$	Popln. at $45/km^2$	Popln. at $118/km^2$
5	1.57E+03	2.20E+04	7.07E+04	1.85E+05
10	1.26E+04	1.76E+05	5.65E+05	1.48E+06
15	4.24E+04	5.94E+05	1.91E+06	5.00E+06
20	1.01E+05	1.41E+06	4.52E+06	1.19E+07
25	1.96E+05	2.75E+06	8.84E+06	2.32E+07
30	3.39E+05	4.75E+06	1.53E+07	4.00E+07
35	5.39E+05	7.54E+06	2.42E+07	6.36E+07
40	8.04E+05	1.13E+07	3.62E+07	9.49E+07
45	1.15E+06	1.60E+07	5.15E+07	1.35E+08
50	1.57E+06	2.20E+07	7.07E+07	1.85E+08
55	2.09E+06	2.93E+07	9.41E+07	2.47E+08
60	2.71E+06	3.80E+07	1.22E+08	3.20E+08
65	3.45E+06	4.83E+07	1.55E+08	4.07E+08
70	4.31E+06	6.03E+07	1.94E+08	5.09E+08
75	5.30E+06	7.42E+07	2.39E+08	6.26E+08
80	6.43E+06	9.01E+07	2.90E+08	7.59E+08
85	7.72E+06	1.08E+08	3.47E+08	9.11E+08
90	9.16E+06	1.28E+08	4.12E+08	1.08E+09
95	1.08E+07	1.51E+08	4.85E+08	1.27E+09
100	1.26E+07	1.76E+08	5.65E+08	1.48E+09
105	1.45E+07	2.04E+08	6.55E+08	1.72E+09
110	1.67E+07	2.34E+08	7.53E+08	1.97E+09
115	1.91E+07	2.68E+08	8.60E+08	2.26E+09
120	2.17E+07	3.04E+08	9.77E+08	2.56E+09
125	2.45E+07	3.44E+08	1.10E+09	2.90E+09
130	2.76E+07	3.87E+08	1.24E+09	3.26E+09
135	3.09E+07	4.33E+08	1.39E+09	3.65E+09
140	3.45E+07	4.83E+08	1.55E+09	4.07E+09
145	3.83E+07	5.36E+08	1.72E+09	4.52E+09
150	4.24E+07	5.94E+08	1.91E+09	5.00E+09
155	4.68E+07	6.55E+08	2.11E+09	5.52E+09
160	5.15E+07	7.21E+08	2.32E+09	6.07E+09

165	5.64E+07	7.90E+08	2.54E+09	6.66E+09
170	6.17E+07	8.64E+08	2.78E+09	7.29E+09
175	6.73E+07	9.43E+08	3.03E+09	7.95E+09
180	7.33E+07	1.03E+09	3.30E+09	8.65E+09
185	7.96E+07	1.11E+09	3.58E+09	9.39E+09
190	8.62E+07	1.21E+09	3.88E+09	1.02E+10
195	9.32E+07	1.30E+09	4.19E+09	1.10E+10
200	1.01E+08	1.41E+09	4.52E+09	1.19E+10
205	1.08E+08	1.52E+09	4.87E+09	1.28E+10
210	1.16E+08	1.63E+09	5.24E+09	1.37E+10
215	1.25E+08	1.75E+09	5.62E+09	1.47E+10
220	1.34E+08	1.87E+09	6.02E+09	1.58E+10
225	1.43E+08	2.00E+09	6.44E+09	1.69E+10
230	1.53E+08	2.14E+09	6.88E+09	1.80E+10
235	1.63E+08	2.28E+09	7.34E+09	1.92E+10
240	1.74E+08	2.43E+09	7.82E+09	2.05E+10
245	1.85E+08	2.59E+09	8.32E+09	2.18E+10
250	1.96E+08	2.75E+09	8.84E+09	2.32E+10

Possible population sizes for shells of given radii.
The shaded portion is the region we should consider first.

Bibliography

εν αρχη ην ο λογος
και ο λογος ην προς τον θεον
και θεος ην ο λογος

This is a list of texts which are instructive, informative and entertaining – including those that been quoted or cited in this document. All of these are recommended reading, including the acknowledged fiction. The annotations are my own, and show my private eccentricities. I neither agree nor disagree with everything that is published in all of these references. For my point of view on each topic read the body of *this* document.

The order here is alphabetic by surname of first known author, or by first significant word of title for anonymous or multi-author publications.

Printed References

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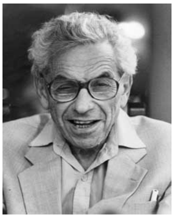
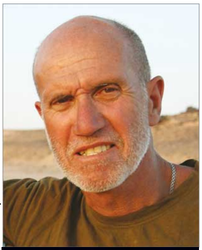
Aign2000 **Aigner, Martin**; **Ziegler, Günter M**.: *Proofs from THE BOOK*. 2000. (second edition) Springer-Verlag, New York. ISBN 3-540-67865-4. Not strictly relevant to this study, but a beautiful eulogy of mathematics, in dedication to Paul Erdős.



Bank1994 **Banks, Iain M.**: *Feersum Endjinn*, 1994, Orbit (Little, Brown and Company), London. ISBN 1-85723-273-9. This is fiction, not fact – and like all of Banks' novels supremely entertaining. I do *not* believe that we will foreseeably achieve the engineering described here, nor in *Excession* (1996) ISBN 1-85723-457-X, *Inversions* (1998) ISBN 1-85723-763-3, *Consider Phlebas* (1987) ISBN 1-85723-138-4 nor *The Player of Games* (1988) ISBN 1-85723-146-5 – but they are *all* worth reading.

Bauv1994 **Bauval, Robert**; **Gilbert, Adrian:** 1994, *The Orion Mystery*, Mandarin & William Heinemann, London ISBN 0 7493 1744 2. This is just the sort of book that does *not* contain the sort of information needed for a serious inter-stellar project. It is great fun, and entertaining – if you like your Egyptology presented that way – but it does *not* have any real scientific grounding. With this book (enjoyable though it is) are to be placed all those other works that try to show that The Ancients built a knowledge of the future into the design of the Pyramids, or that Stonehenge "proves" we have been contacted from outer space, or that the Maya once had the engineering required for rocket technology. I have a number of these books in my private library, and I enjoy them greatly – but I also enjoy science-fiction and fairy stories, without supposing these to be representations of scientific reality, either!



Beat2001 **Beatty, J. Kelly:** 2001, *NEAR Falls for Eros*, In Sky & Telescope, May 2001, Vol. 101 No. 5, Sky Publishing Corp, Cambridge, Mass. This article includes close-up pictures of *433 Eros* – very close up – and briefly discusses it surface and the interior makeup both of *433 Eros* and *253 Mathilde*.

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amount, we are taken from a simple human scene – one way towards the sub-atomic particles, and the other way towards the largest structures in the universe that we know. This book has been copied since, and all its alternative incarnations will begin to give you an idea of just how big space is – and just how small an atom is. Since the 1950s we have added ideas about the steps both above and below the series in this book – but just 40 jumps, each a power of ten, is a huge distance. A good way to stretch the mind.

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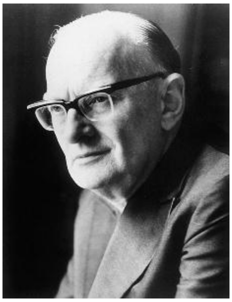

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Final Report (accessed from the internet) An update on the technology required to build a space elevator. This, and the previous work cited by Edwards, is essential reading. Without the Space Elevator – or an equivalent – we are going nowhere.

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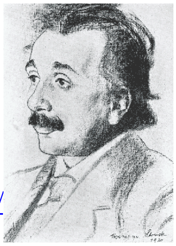

[We are used to seeing Albert Einstein as an older man. The illustration here is how he appeared when he first expounded the Theory of Relativity.]

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Luck1998 **Luck, Steve** (Ed.): 1998, *Philip's Science & Technology Encyclopedia*, George Philip Ltd., London, ISBN 0-540-07642-2. Although this is a book for children and adolescents, it contains the bulk (but not quite all) of the scientific information needed to understand *this* description of interstellar travel. Do not imagine, though, that the real construction of an interstellar ship is going to require just this level of knowledge! <<<CHECK SPELLING

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Pull1995 **Pullman, Philip:** *His Dark Materials* (Trilogy: *Northern Lights* [ISBN 0-439-99412-8], *The Subtle Knife* [ISBN 0-439-99413-6] and *The Amber Spyglass* [ISBN 0-439-99414-4]), Scholastic Press, London. These are – strictly speaking – completely irrelevant to this topic: but these books (a) *do* teach you that good writing is seductive, and (b) show you that thinking about alternative and new worlds is not as straightforward as you might like to suppose.

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Syke2001 **Sykes, Bryan:** 2001, *The Seven Daughters of Eve*, Bantam Press, London, ISBN 0593 048369. This gives us some idea of the rather small number of ancestors that are required to ensure genetic diversity. From the conclusions and observations of this book we can have at least some confidence that 2,000 people would make an adequately rich starting population for long-term breeding. Now are *you* descended from Helena or Jasmine or Katrine or Tara or Ursula or Velda or Xenia or … was there another daughter?

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Quote from synopsis: "*Einstein's equations of general relativity are solved in terms of gravitational potential derivatives, with the energy-momentum tensor T(mu-nu) equal to mass and/or field energy, such that T(mu-nu) does not equal zero outside a body. The line element equation then describes the variance of test particle internal geometrical structure and time-rate due to work done in a field, not the space-time curvature. Specific properties of gravitational fields and bodies come from this new solution: (1) The gravitational field consists of electromagnetic spin 2 gravitons which produce the gravitational force through the magnetic vector. (2) The gravitational mass is the Newtonian mass, not the relativistic mass, of a moving body. (3) An 'action principle' exists in gravitation theory. (4) Attractive gravity exists between matter and antimatter. (5) Unification with quantum physics appears possible.*"

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Directory – the root of a tree of links to space pages on the web. Accessed 20031122.

Surv2007 http://survive2012.com/why_2012_maya.php Accessed 20071001. Will the world end in 2012?

Ther2005 http://www.theregister.co.uk/2005/08/09/papyrus_nuclear_waste/ Accessed 20071031 How nuclear waste is being documented on papyrus – or a modern equivalent, to ensure the records last for thousands of years. "Permanent paper" is not quite the same as papyrus, but is the nearest modern equivalent (according to its manufacturer).

Thin2007 http://library.thinkquest.org/19455/terraforming_calculations.htm Accessed 20071115 Considers the Terra forming of Mars – not an entirely scientific analysis, IMHO.

Tran2007 http://transcripts.cnn.com/TRANSCRIPTS/0708/11/acd.01.html Accessed 20071031 Oxygen requirement for sustained human life is stated here as being 16% of the air. Ordinary atmospheric oxygen content is about 21% and in each breath we absorb up to 4%.

Unkn2003 Unknown, 2003, *Life and Its Environment*, eem603pptpart_7.pfd

Unst2000 http://unstats.un.org/unsd/demographic/products/dyb/2000_round.htm Accessed 20071026 large number of world statistics

Wein1945a http://en.wikipedia.org/wiki/Dialect Accessed 20070930

Wein1945b http://everything2.com/index.pl?node_id=984105 Accessed 20070930

Wiki2007a http://en.wikipedia.org/wiki/Image:Rama16wiki.jpg Accessed 20070921

Wiki2007b http://en.wikipedia.org/wiki/Image:Ring_of_Cheops.jpg Accessed 20070921

Wiki2007c http://en.wikipedia.org/wiki/Henry_Moore Accessed 20071001

Wiki2007d http://en.wikipedia.org/wiki/Joseph_McCarthy Accessed 20071006 An example of suppression of freedom of thought, excellently described within this Wikipedia article.

Wiki2007e http://en.wikipedia.org/wiki/Spheroid Accessed 20071011

Wiki2007f http://en.wikipedia.org/wiki/Image:William-Adolphe_Bouguereau_%281825-1905%29_-_Invation_%281893%29.jpg Le Guêpier – Wasps's Nest Accessed 20071025

Wiki2007g http://en.wikipedia.org/wiki/Pirahã_people Accessed 20071101 A group of people with a very simple language, who choose not to count, and can whistle their communications. They have the smallest set of phonemes ever – just seven consonants and three vowels.

Wild1895 http://en.wikipedia.org/wiki/The_Importance_of_Being_Earnest Accessed 20070930 – *The Importance of Being Earnest*. Text at http://www.gutenberg.org/etext/844 Accessed 20070930

Wild1899 Prin2001 http://www.princeofwales.gov.uk/speechesandarticles/a_speech_by_hrh_the_prince_of_wales_titled_hospital_design_n_851630621.html (Oscar Wilde and wallpaper) Accessed 20070930

Worl2007 http://www.worldmapper.org/images/largepng/2.png population size map Accessed 20071016

Zapp2000 **Zappalà, V**.; **Cellino, A**.; **Dell'Oro, A.; Paolicchi, P**.: 2000, *Physical and Dynamical Properties of Asteroid Families*, in Asteroids III, ?, ?, isbn ?

Glossary

AFAIK	As Far As I Know
Alpha	The first letter of the Greek alphabet (see page Error: Reference source not found). Stars in a constellation may be named according to their perceived brightness – with the alpha star being the brightest, the beta star the second brightest, and so on.
AU	Astronomical Unit. The mean distance of Terra from Sol.
Density	The mass per unit volume. This is usually measured in grams per cubic centimetre (or kilograms per litre), which makes the density of water (by definition) 1.0
FYI	For Your Information
Gpa	Giga Pascal. A Pascal is one Newton per square metre, or one Joule per cubic metre, so a Giga Pascal is one thousand million Newtons per square metre $10^9 N/m^2$
IMHO	In My Humble Opinion
Lightyear	The *distance* light travels in a year
Luna	The Moon – the major natural satellite of the Earth (Terra).
NGC	New General Catalogue
OSHA	The United States Occupational Safety and Health Administration
Palindrome	Definition in mirrored form, mirrored in definition.
Parsec	The *distance* at which a triangle with base 1 AU has its vertex angle equal to one arc second.
Plasma	One of the four main states of matter (the others being Solid, Liquid and Gas), in which atoms are dissociated, and the sub-atomic particles are not bound fixedly to each other. This is the state of most of the matter inside most of the visible stars.
ppmv	Parts per million by volume

Regolith	The fine dust covering an astronomical body. The footprints on the moon are footprints in regolith. We currently believe that most asteroids will be coated in regolith of varying thickness.
Scalar	An ordinary value – just a number. This contrasts with vectors, arrays (matrices) and tensors. Mass, Time and Distance are all scalar measures.
Sol	The Sun – the nearest star, round which the Solar System rotates.
Terra	The Earth – the planet upon which we live.
Vector	A multi-valued term. This has to be represented by more than one number – a row of numbers. Velocity is a vector quantity, as it requires specification of both Speed and Direction. Location is a vector quantity, in that it requires specification of three values (for example, how far up, how far right, how far in from the reference point).
Voyager	Two satellites, launched from the USA in the 1960s, which have travelled beyond the Solar System – the first man-made objects to do so.
WOLOG	WithOut Loss Of Generality

Greek alphabet

Α α	**Alpha**	A
Β β	**Beta**	B
Γ γ	**Gamma**	G
Δ δ	**Delta**	D
Ε ε	**Epsilon**	E (short)
Ζ ζ	**Zeta**	Z
Η η	**Eta**	E (long)
Θ θ	**Theta**	Th
Ι ι	**Iota**	I
Κ κ	**Kappa**	K

Λ λ	**Lambda**	L
Μ μ	**Mu**	M
Ν ν	**Nu**	N
Ξ ξ	**Xi**	X, Ks
Ο ο	**Omicron**	O (short)
Π π	**Pi**	P
Ρ ρ	**Rho**	R
Σ ς σ	**Sigma**	S
Τ τ	**Tau**	T
Υ υ	**Upsilon**	Y, U
Χ χ	**Chi**	Kh (guttural)
Φ φ	**Phi**	F
Ψ ψ	**Psi**	Ps
Ω ω	**Omega**	O (long)

Wasps' Nest - Bougereau

[redacted]

Illustrations

The illustrations are drawn from a wide variety of sources – some public, some personal. Each tries to illustrate something of the human and scientific aspects of this discussion.

Cover: A solar flare, colours inverted from source.

p.41: The Earth (Terra) – Eastern view

p.Error: Reference source not found: Armstrong and Aldrin, Apollo 11, the first men on the Moon (Luna)

p.Error: Reference source not found: the scattering of the asteroids in the asteroid belt. The outer ring is the orbit of Jupiter; the two inner rings are the orbits of Mars and Earth (Terra).

p.Error: Reference source not found: the author, standing in a PowderHorn library – at the time of writing, part of the largest single database in operation.

p.Error: Reference source not found: On the Voyager spacecrafts there were golden disks that indicated something about the position and development of mankind. Other than radio transmissions, these were our first extremely long-distance communications.

p.8?: Witches Broom Nebula, NGC 6960, colours inverted

p.9?: World Population Growth, as predicted by the US Census Bureau in 2003. In my humble opinion (IMHO) this gives figures far below what we will actually experience.

p.Error: Reference source not found Earth crescent

p.Error: Reference source not found: close up of a sunspot

p.Error: Reference source not found: Messier 74 – a beautiful spiral nebula – colours inverted (negative)

p.Error: Reference source not found: Bruce McCandless flying free in space, 1984

p.Error: Reference source not found: Fear and Hatred – the two moons of Mars. This one is Phobos (Fear) – very non-spherical.

p.Error: Reference source not found: a tadpole p.Error: Reference source not found: some selected asteroids, of various types

p.Error: Reference source not found: if you are in the right place at the right time (a very narrow strip on Terra's surface, for a very few seconds of time) it is possible to take pictures like this – the international space-station just at the terminator of the moon.

p.Error: Reference source not found: Saturn

p.Error: Reference source not found: an early illustration of the Orion project – a ship propelled by small nuclear explosions, whose impulse is "cushioned" onto the ship by the large baffle-plate at the back

p.36: There are planets in every direction. If there are planets in the Alpha Centauri system (and we know neither whether there are or there are not), then these are the regions in which life-sustaining planets could orbit.

p.Error: Reference source not found: the comparative sizes of the Sun (Sol) and the three stars of the Alpha Centauri system

p.Error: Reference source not found: A photograph of London at night, taken from an orbiting satellite.

p.Error: Reference source not found Eros regolith

p.Error: Reference source not found: NASA – amongst others – has looked at what it would take to create distant habitations. This is an illustration of one of their ideas.

p.Error: Reference source not found: a strip of the surface of Mars

p.12: Time does not change. Hieronymus Bosch, on the doors of the triptych *The Garden Of Earthly Delights* illustrates the fourth day of creation (according to the alchemists). The new-born Earth coalesces out of timeless blue mists – magical.

p.24: The USA by night – personally, I am not convinced that this is a real photograph!

p.Error: Reference source not found: another strip of the surface of Mars

p.Error: Reference source not found: Nuclear fission does not take much matter to produce much energy: this ball is the amount of Plutonium that could have been used in creating the Nagasaki bomb.

p.Error: Reference source not found: yet another strip of the surface of Mars

p.29?: the relationship between the Minkowski factor and relative speed.

p.52: three asteroids: *Mathilde* (loose carbon accretion), *Gaspra* (small and dense), and *Ida* (the satellite with a moon - *Dactyl*).

p.Error: Reference source not found: *433 Eros* – a possible candidate for an early ship.

p.Error: Reference source not found: the orbit of *253 Mathide* in relation to the inner planets

p.Error: Reference source not found: a small section of a wasps' nest

p.Error: Reference source not found: the background radiation of interstellar space

p.Error: Reference source not found: a complete wasps' nest, sectioned to show the inner structure

p.Error: Reference source not found: ?? flying free in space

p.Error: Reference source not found: a sketch of how a hollowed asteroid might be constructed.

p.Error: Reference source not found: *433 Eros*

p.Error: Reference source not found: the Schiaparelli Basin – a crater on Mars (0.15°N, 345.6°W).. This is named after the astronomer ? ? Schiaparelli, who first suggested there were "canals" on Mars – and not after his other relatives who designed clothes, ? ? Sciaparelli, or painted pictures, ? ? Sciaparelli. **<<<INSERT DETAILS<<<**

p.Error: Reference source not found: the Lorentz Transformation

p.Error: Reference source not found: the rings of Saturn, close-up

p.Error: Reference source not found: a complete lunation. Note that Luna shows *almost* the same surface to Terra at all times – almost, but not quite – as you can see from the "wobble" during the lunation.

p.Error: Reference source not found: how the carbon atoms would be arranged to make a bucky-tube. This is one possible material for the "ribbon" of the Space Elevator

p.Error: Reference source not found: Mars

p.Error: Reference source not found: Antique glass bottles

p.Error: Reference source not found: the ratio of the elements in the universe – showing that it is mostly hydrogen, with some helium, and only 0.1% of everything else. Although we are "star stuff" we are (it seems) the unimportant part of star stuff.

p.Error: Reference source not found: the observed proportions of elements on Earth (Terra). These are not necessarily the proportions that we will need on the ship, but do give us some idea of the difference between interstellar matter and what we need to be surrounded by

p.Error: Reference source not found: the observed proportions of elements in living matter on Earth (Terra).

p.Error: Reference source not found: the ratio, in the ship, of the five main categories of matter: structure, engineering, biome, cargo and ejecta.

p.Error: Reference source not found: some symbols of religions and philosophy. We cannot do without deep thought, especially in such constrained environments.

p.Error: Reference source not found: the ratios of the elements on Earth (Terra), in life-forms and on the ship.

p.Error: Reference source not found: the ratios of some elements on Earth (Terra), in life-forms and on the ship.

p.Error: Reference source not found: The Earth (Terra), Western View

p.Error: Reference source not found: food

p.Error: Reference source not found: Benjamin Kelly, when only 2 hours old. New life.

p.Error: Reference source not found: Chris and Louise Bland. New bonding.

p.Error: Reference source not found: Gay Kelly. Motherhood and culture.

p.Error: Reference source not found: the cousins (clockwise from the bottom): Benjamin, Anthony, Miranda, Louise, Veronica, Rebecca, Edward, George. Youth and joy.

p.Error: Reference source not found: Benjamin Kelly and his Grandmother, Vera Kelly. The linking of generations.

p.Error: Reference source not found: the launch of ?????

p.Error: Reference source not found: World Population Growth

p.Error: Reference source not found: the overcrowding of man

p.Error: Reference source not found: World Population Growth, as predicted by the US Census Bureau, 2003.

p.Error: Reference source not found: satellite view of Earth (Terra)

p.Error: Reference source not found: Population Growth Rates in some countries

p.Error: Reference source not found: Hoag's Object , NGC 6028 – a ring nebula (with, visible in the gap, another more distant ring nebula). [Hoag1950]. There are several theories as to the techniques of formation of ring nebulæ – but (as yet) we do not know which one is nearest the truth.

p.Error: Reference source not found: a stellar explosion, M ???

p.Error: Reference source not found: the Himalayas, as photographed by satellite

p.Error: Reference source not found: the Moon (Luna)

p.Error: Reference source not found: My grandparents – times past

p.Error: Reference source not found: Background microwave temperature

p.Error: Reference source not found: Messier 51 and NGC5195

p.Error: Reference source not found: Pioneer greeting – our message on the Pioneer spacecraft

p.Error: Reference source not found: Benjamin and Miranda Kelly – times future

p.Error: Reference source not found. Hieronymous Bosch, The Garden of Earthly Delights (doors – an extract)

p.Error: Reference source not found: Miranda Kelly

Colophon: David Marsden, dear friend, who made it to the stars before me. RIP.

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Colophon

Per Ardua ad Astra

1Cor13:11 When I was a child, I spake as a child, I understood as a child, I thought as a child: but when I became a man, I put away childish things.

1Cor13:12 For now we see through a glass, darkly; but then face to face: now I know in part; but then shall I know even as also I am known.

1Cor13:13 And now abideth faith, hope, charity, these three; but the greatest of these is charity.

[illegible]

[illegible]

i Consider how much we currently spend on military defence. This amounts to at least $1,000 per person per year. The costs in the USA of defence are about $4×10^{11}$ (Ref: [Dona2003] *et al.*) per year, to guard the safety and interests of fewer than 3´10^{8} people. If we are guarding the continued safety of *all* people – that is, all our human survivors – then, surely, we should consider paying a larger price, and be happy with it.

If we just equal the USA expenditure at $1,000 per person per year for the 6×10^{9} people on the planet, we have 6×10^{12} dollars per year. This is enough to hurt. Even if we consider just the top 700 million people (7×10^{8}) – the top ten percent economically – then we have $7×10^{11}$ per year – and we could afford that in Europe, the USA, Japan, Australasia, and the economically developed countries elsewhere.

The cost of a single Saturn V rocket is from $6×10^{9}$ to $1×10^{10}$; the cost of a Shuttle is $2.1×10^{9}$ and the cost of a Shuttle launch is about $5.0×10^{8}$ (Ref: [Olli2002]); and the cost of an Ariane launch is $1.6×10^{8}$ (Ref: [Olli2002]). Hence for this sum of money we could (it seems) afford several thousand Shuttle launches per year – that's enough to get a *lot* of material into orbit. It's also completely unrealistic, and inefficient.

ii More accurately, the speed of light *by definition* is 299,792,458 m/s or 299792.458 km/s – which is very close to 300,000 km/s … a much easier number to remember. In Ref [Wiki2006b] there are forward pointers to more information – including the equivalence of this speed to 1,079,252,848.8 km per hour or 186,282.397 miles per second or 670,616,629.384 miles per hour. Grace Murray Hopper used to call this "one foot per nanosecond": see Ref [Wiki2006c].

iii If we take the observable universe to be $13·10^{9}$ years old (ref: [Spac2004] – which gives the rather wide range 11.2 – $20·10^{9}$ years), or $13·10^{9}$ [years] · $3.1·10^{7}$ [seconds in a year] · $3·10^{5}$ [*c* in kilometres per second] · 10^{3} [metres in a kilometre] metres across, this gives a maximum possible journey (requiring science fiction to complete) of $13·10^{9}·3.1·10^{7}·3·10^{5}·10^{3} = 13·3.1·3 · 10^{24} = 1.2·10^{26}$ metres (1.2E+26). This, folks, is the absolute upper bound!

iv This, incidentally, would limit the acceleration to only a small value. A large (forward) acceleration as well as being difficult to achieve implies a large slope on the floors. When that acceleration is stopped (as, eventually, it must be) then the sloping floors become less useful. If we want to have large accelerations – which, in any case, are very difficult to achieve – then we also have to be able to accommodate floors that can be dynamically levelled. This levelling may not be required for several hundreds of years after construction.

It seems better, therefore, to limit the (forward) acceleration to below 0.05*g* – or about 0.0510*m/s/s* (meters per second per second). Even this implies a floor slope of about 5° (five degrees). As will be seen later, we do not anticipate even this large an acceleration.

v To put this into perspective, the Sun (Sol) through radiation alone looses 4 million tonnes per second – and possibly even more due to solar wind.

vi There is some discussion as to whether Pluto is actually a planet or not (apparently now "resolved" by saying it is <u>not</u> a planet , but a minor planet). There is the new, possibly tenth, planet called Sedna, and an eleventh called Eris … and (it turns out) may others. Whether planet or not, whether outermost or not – the figures quoted here give us some idea of the scale of the problem. There is even talk (in 2005) of a twelfth or thirteenth or… planet [2003 UB313 "Xena"/ "Lila", 2003 EL61, 2005 FY9, Quaoar, Orcus …] (with deep, pointless considerations as to which are to be considered as planets, which as planetoids, which as asteroids, Kuiper Belt objects, etc.). IMHO J the next planet should be called "Rupert", in honour of Douglas Adams J Ref. [Adam2002] *et seq*.

vii There is a lot of spurious information spread concerning radiation. I agree that radiation causes cancers and genetic mutations and deaths – but the human species is remarkably adaptable: we can survive *as a species* quite a lot of exposure – very much more that we can survive *as individuals*. We might have to allow, in our spaceship, for (i) shorter life-expectations, and (ii) higher numbers of genetically damaged offspring, and (iii) a greater density of (acceptable) mutations. I do not expect our interstellar offspring to have two heads or three legs – but we cannot be absolutely certain that their mean height and body-mass and skin-colour will have the same variations that we have on Terra. We may even evolve a more “radiation-tolerant” strain of *homo sapiens*. Remember again that what mankind can survive *as a species* is different from what an individual can tolerate. In this exercise we have to consider primarily the species, not the individual.

viii Where density is not known, the values of 1.6 and 2.5 are assumed, and the two masses given are for those densities. Where the density is known, the mass is calculated at that density. Each asteroid is assumed to be either smoothly spherical, or (where varying diameters are known) smoothly ellipsoidal. In each case this will give a value that is too large. Some known masses are taken from the very helpful http://www.nineplanets.org/data1.html accessed on 20030102, and other sites (see bibliography).

ix *3753 Cruithne* has the great advantage of being very nearby – it is co-orbital with the Earth (Terra) and hence would not take a long time to reach. Anything that’s within 0.5 AU looks like a good idea! Note that it is *not* a moon of the Earth (Terra), as it does not orbit (as its primary centre) the common centre of mass between it and the Earth – it primarily orbits the Sun (Sol) and is locked into its current orbit by (a) being at (roughly) the same distance as the Earth (Terra) and (b) tidal (orbital) locking (resonance) (see [Vamp2005]).

x This is scheduled to be a mere million miles from Terra on the 29th September 2004 – and to make several more close approaches in following centuries. Although it is a little small, perhaps *4179 Toutatis* should be considered as an early candidate, merely because of its accessibility. Object 2007 RS1 came by at about 50,000 miles in September 2007. And *99942 Apophis* will pass at than 35,000 km. (that’s about 21,500 miles) in April 2029. And if you *really* want to worry, then the 17th March 2880 is a date to look forward to, and asteroid 1950DA. It is estimated to miss Terra by roughly zero miles. [Nasa2002]

xi My own violin teacher, Mr. S. Montagu Cleeve [1894-1993], was both an engineer and a musician. He played the viola d’amore, and made in it some engineering design changes (in the number of sympathetic strings that run under them main bowed strings). Whether these design changes have caught on I do not know: I suspect that he learnt the viola d’amore by picking an old one up and trying to play it, and not from a teacher – it was a skill re-found, and not taught.

xii It is still doubtful – at current estimates – whether we can transport enough power, and generate enough power, in the absence of a nearby star, to keep human life in the suggested quantities for millennia. One suggestion has been to use only a small amount of energy to accelerate the ship, whilst it can get that energy from (say) Sol, and then just wait even longer for the journey to take place. That is, we accept a very much lower top speed – a speed (perhaps) just exceeding the escape velocity of the Solar system. This would make (at 30 km/s or 0.0001*c*) the one-way journey to Proxima Centauri take over 4,200 years. Even at 0.001*c* or 300 km/s we are talking about the shortest first leg of the trip being over 420 years.

xiii Remember that there should always be an even number of airlock openings – one to let the crewmembers out, and another to let them back in. I presume that we are sufficiently civilised that we will *not* have capital punishment?

xiv There have been many science fiction stories about ships that have no external view. It may be that our ship will be like that – to cut down on heat radiation (we do not want the crew to freeze) and received radiation damage (from cosmic rays, and other energetic sub-atomic particles, which might have a carcinogenic effect). This may have powerful psychological effects upon the travellers.

xv This is one reason why I have suggested such a large mass of air (and air replacement). Note that the very rock of which the asteroid is originally made may itself contain oxygen as part of its structure. If the asteroid (and this assumes we *are* building our ship round an existing asteroid) is M type, however, then it will provide us with little or no oxygen, being made largely of Ni-Fe (nickel-iron).

xvi For example, to achieve pseudo-gravity of 1.1g (10 metres per second per second) in a ship of radius 6 km along the axis of rotation, it needs to spin at one revolution every 6E+5 seconds – say one rotation every sixteen and a half hours. This is not a very fast rotation to get a comfortable – if rather high – pseudo-gravity. Humankind can easily deal with lower gravities – anywhere in the range 6 m/s to 10 m/s. See Ref: [Hume2001]. Note that *some* gravity is essential for health. If gravity is too low humans quickly lose bone strength.

xvii There are other, less obvious, design features also required. I was reminded of this when visiting, as a tourist, the old large ship *Queen Mary*, and observing that the corridors are curved – being higher at each end than in the middle. You would introduce this element of design only after having experienced high seas – it is not intuitively obvious to a landlubber.

xviii Even Terra is unstable. We are sure that Sol will become a nova in less than six thousand million years from now. We do not know whether there will be any large meteoric or cometary impacts upon the earth in the reasonably near future. Such impacts would have massive effects upon the life-forms on earth. Indeed, past impacts may well have triggered the catastrophic changes that (for example) wiped out the dinosaurs, and brought about the ascendancy of the mammals.

All environments are unstable – what we have to measure and judge upon is the *degree* of each particular environment's instability, and its acceptability – its risk.

xix This ratio of "man-to-other" is growing depressingly fast. We seem, as a species, to be trying to convert the bulk of the land-based biomass into human bodies. We can do this successfully only up to the point when we can grow no more food for ourselves – and then it is too late. When we reach the stage that we have only just enough cows, only just enough sheep (etc.) to support humankind, then the population will plummet. And, I fear, we will lose the cows and the sheep – and much else as well (perhaps *all* else as well) – at the same time.

xx "Propellant" (ejecta) is that very large amount of stuff that is (ultimately) chucked out the back of the ship to give it forward momentum. It is, initially, the core of the hollowed asteroid – or the tethered asteroid, for a shell-constructed ship. This section does *not* include the machinery for propulsion.

In the "Ship Structure" we are assuming a hollowed asteroid of the size of *433 Eros*. We are also assuming that the ship is strong, and that it contains quite a lot of internal structure – spaces to live in.

"Active Baggage" means machinery, tools, books, furniture and so on. This is the material which is carried and is of some use in its current form, and is not a raw source of matter for other uses. It includes communication equipment, computers and musical instruments.

"Power Supply" is enormous. It includes any reactors, and propulsion units. It includes the power transmission equipment.

Under "Atmosphere" we are assuming a Terra-like atmosphere at 2,000-ft. pressure. This reduces the total outward push on the walls of the ship without appreciably impairing the biological stability of the system. The pressure assumed is 710 mmHg or 94.5 kPa., calculated from [Hype2005].

“Living Matter” includes people, animals, plants, fish, birds and insects. It includes the cattle, the crops, and the compost heaps. The absolute quantity of this can fluctuate – indeed, *will* fluctuate – during the voyage. But the total mass of this plus the “Raw Matter” will remain constant through the voyage.

“Water” is all the free water in the ship, other than that in the living matter itself. That is, the water in the cells of the herring are counted as Living Matter, but the lake it swims in is counted as Water.

“Raw Matter” is just “stuff”. That is, it is metal and stone and plastic etc. prior to being put to active use. The raw matter will be used to make useful objects, just as (for example) iron ore is used as the originating source for knives and needles. The Raw Matter also includes the non-organic parts of the soil (the stone and sand, etc.).

xxi To fully understand just this one poem – if any poem can ever be fully understood – you need some access to the Latin, Greek, German, French, Italian, and Sanskrit languages, as well as the Cockney (London) dialect of English – and a huge list of external literary influences. But it is not, because of that, elitist: it is a crossing point, a swirl of cultural links and symbols.

xxii Greek and Roman sculptures were very often painted by their originators. We tend to think of them as pure, monochrome shapes – but many of them used to have painted eyebrows, coloured lips, and skin the colour of skin, not stone. Our fashion of looking has changed to deny us this as a possibility for those statues – but not denied to more modern works.

xxiii Auschwitz, Guantanamo, Guernica, Darfur, annihilation of Tasmanian natives, and symbolically, to remind us of much more, Tiananmen Square (天安門大屠殺). For every man killed in the First World War, ten horses died. At the time of writing, more than a thousand people die *per day* in South Africa as the result of HIV/AIDS because of *political* (not financial or medical) posturing. This endnote, if complete, would be longer than The Library of Congress considered as a single work.

xxiv Pope, cardinal, archbishop, bishop, priest, dean, laity – though officially there are just three layers over the laity: the Pope, then the Bishops (with subordinate titles of Cardinal, Archbishop and Bishop), then the priests (with numerous subordinate titles, including deans).

xxv Field Marshal, general, Lieutenant-General, Major-General, Brigadier, Colonel, Lieutenant-Colonel, Major, Captain, Lieutenant, Second Lieutenant – and the non-commissioned Sergeant, Corporal and Lance-Corporal, all over the Privates. This is often stated more simply as: Private, Corporal, Sergeant, Lieutenant, Captain, Major, Colonel, Brigadier, General, Marshal.

xxvi To each of us the past is lost, and for us, the places that we do not ourselves experience are partially or wholly lost. And for all, the future is in the same place as the inexperienced present or the forgotten past – it is in the unknown. We are all explorers of the unknown, travellers and earthbound, who must not bemoan not having what we cannot have and refusing to enjoy the good things that we *can* have.

xxvii We know that certainly there are more than 2,000, and though this is controversial and despite the number of language names, we are fairly sure there are fewer than 6,000. The number of speakers of a single language range from over one thousand million, to just one – a language which is about to die.

xxviii We have a real example of this: the BBC Domesday Project recorded data on specially-made CDs, intending to preserve that information for centuries – and then the machines for reading these special CDs became obsolete, and after some years, new copies of the discs had to be made, matching the new technology. [REF]

xxix Note that "trillion" here is the American trillion 1E12 – a million million (the traditional English billion). This estimate of Sagan's, though, is perhaps a little high: currently [2005] the official Defence budget is (about) $5E11 (five hundred thousand million dollars) per year – half of Sagan's figure – see [Defe2005]. USA Defense spending is increasing at more than three times the non-military inflation rate. Clearly, this cannot continue for long. See [Gmil2005]

xxx We do not even know how many different *species* of creature there are on the planet: estimates vary between three million and a hundred million. If we assume that there are just ten million species (a reasonable estimate), and that (currently) we are losing at least three species every week, 150 per year (which is a lower bound), then in 66 thousand years (and that is *not* a very long time!) we will have annihilated everything. But as some species go, they will trigger many others to go in response – just imagine what would happen were we to lose the grasses – grass and rice and wheat and bamboo – what would survive thereafter?

xxxi Thor Heyerdahl observed that between two of his Atlantic voyages (Kon-Tiki [Heye1950], Aku-Aku [Heye1958] and Ra [Heye1971]), the ocean – the mid-ocean – had become so dirty that his crew could no longer rinse their toothbrushes overboard.

xxxii "Global Warming" does not mean that everywhere is getting warmer. What it does mean, though, is that by 2050 Miami will be a submarine city. The large majority of humankind lives near the sea and depends upon the produce of the land close to the sea. A small rise in ocean levels, therefore, has a disproportionately large impact. And the oceans are rising now. Strange to realise, isn't it, that the motor car will both drown us and starve us too?

xxxiii We now know that the North Polar ice is melting, and that by 2040 there will be, in Summer, no ice at the North Pole. This is a recent (November 2004) surprise – and not a pleasant one. As the North Atlantic loses salinity there will be huge effects upon the course of the Gulf Stream, and consequent (large) effects upon the temperature of Western Europe. [REFS]

xxxiv These graphs show the (theoretical) world population from 1999 onwards, on the basis of various birthrates. The *x* axis is in years from 1999, and the *y* axis is thousands of millions of people. And, yes, this graph *does* show that we could (theoretically) get to 160 thousand million people by the year 2076. The next graph shows that we could get to over thirty million million people before the year 2200 under the same assumptions. It is clear that we *cannot* get there in reality!

xxxv 8.9 is (IMHO) too optimistic; 36 is (again IMHO) too pessimistic – I think we would have been annihilated (as a species) before reaching that figure – but I would (were I a betting person) lay money on our being *at the very least* 11 thousand million by the year 2045. Tell me, do *you* want twice as many people living in your town, in your street, in your house as you have now?

xxxvi Atmospheric CO_2 is now about 0.038% by volume (or 380 ppmv.), having been – up to about 1750 – at the level of about 270 ppmv., or (during ice ages) even lower at 180-210 ppmv. See also ref. [Geog2005]. Atmospheric concentrations of CO_2 of 4% or greater have been classified (by the OSHA, amongst others) as “immediately dangerous to life and health”.

xxxvii The only organizations or collections large enough and wealthy enough to carry out such a project would be (currently) the United States of America, the European Union, China (given just a few more years), and the United Nations (drawing upon all of these, and others). The other large countries (*e.g.* Brazil, India, Canada, Russia) do not, as yet have sufficient spare resources. Ideally this should be a planetary decision, with planetary involvement, drawing resources from many countries.