An Architecture for Survival

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1. INTRODUCTION

Here is the problem. In the very long term, life on planet Earth will no longer be possible, due to a number of astronomical developments. In the short term, it is hard to address this reality, because of the associated financial and political challenges. Is there a way forward, which makes incremental steps towards being able to deal with the existential threat, while remaining within acceptable financial and political constraints? In this paper, a possible solution is proposed, which uses a combination of commercial objectives with governmental developments, and which leads to an essential first step. The architecture proposed therefore serves both commercial and governmental purposes, while being incidentally, in its essentials, an architecture for survival.

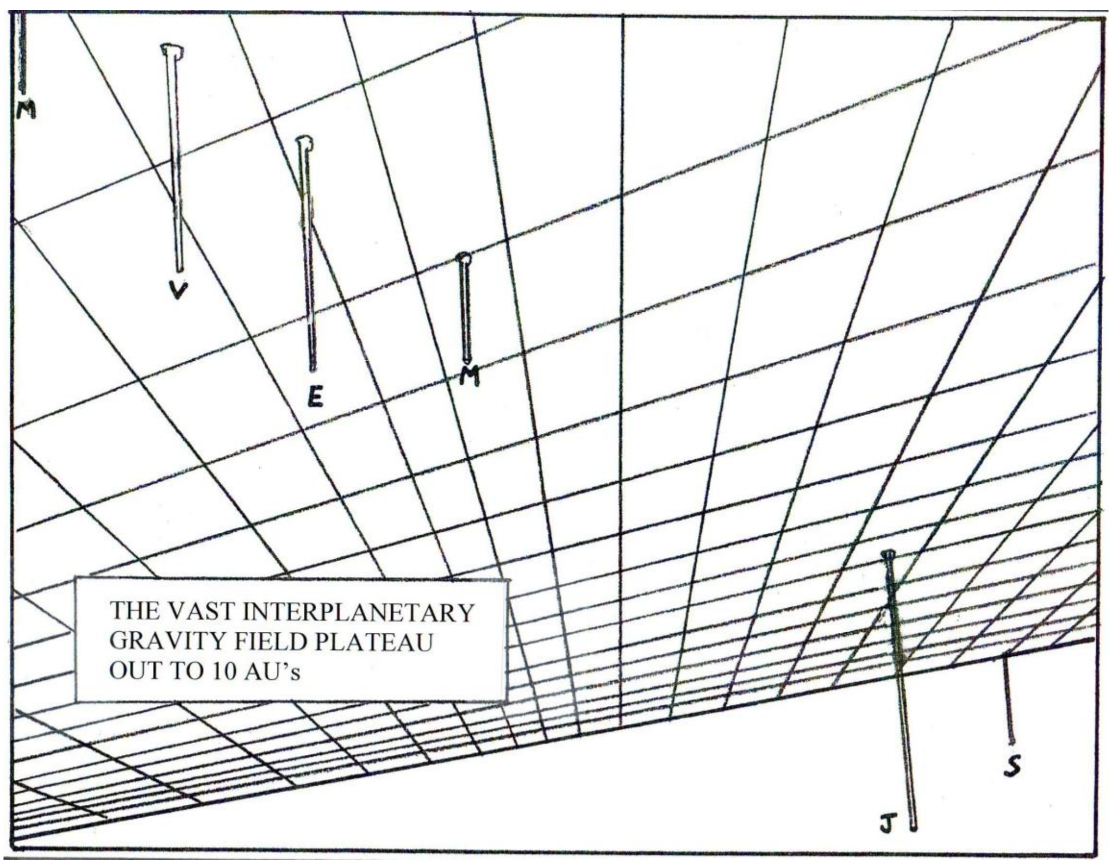
2. THE SETTLEMENT IMPERATIVE

Is there any doubt that in the long term, mankind will need to seek another home due to the demise of our present home on Earth? Reference 8.1 cites a number of sources who have explained the inevitability of this outcome. Of course, we must stress here that this is in the *very* long term. The kind of event which would have this impact would be the eventual expansion of our sun as it swells to become a red giant, or a major bombardment by asteroids, or supervolanoes erupting under Yellowstone, or a magnetic pole reversal, or even human-induced follies, such as a nuclear winter. In fact, it is a consequence of the very long term timescales involved, that it is difficult for the problem to be addressed in the short term via the medium of annual budget cycles for space agencies, etc. If there were something catastrophic forecasted to happen within ten or twenty years, then we could be sure that there would be no problem in raising the funds in order to avert the catastrophe. The trouble is, to make it possible to move millions of humans, and representative plant and animal life, from the Earth to some safer haven, could be a task which takes decades, if not centuries. So, we need to be thinking through the steps that will make it eventually possible to escape, while meanwhile moving steadily forward, even if only incrementally.

The good news is that in our lifetimes we have made a very good start. We already know how to perform a crewed landing on the Moon. And we have sent interplanetary probes throughout the solar system and are even discovering exo-planets outside of it. All we need to do is make the research and development and operations necessary to keep on moving forward. We shall, for example, need to research in particular how to use planetary materials to produce oxygen and water and rocket fuel. We shall see in the next section that the toughest part is in any case getting out of Earth's gravity well in the first place, and we already know how to do that. We just perhaps need a reminder of the ultimate survival imperative to make sure that we always have that background focus and motivation for our work (Ref 8.2).

3. GRAVITY WELLS

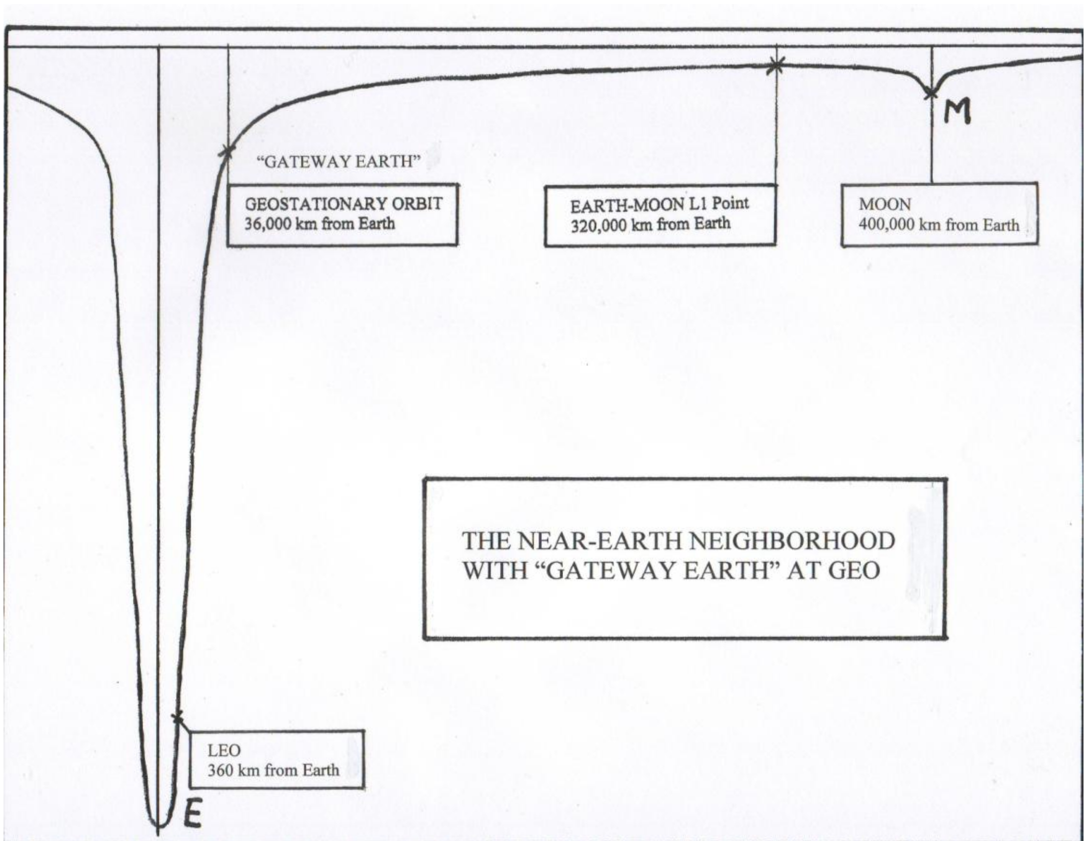
Newton's laws of motion, because of the inverse square law of distance, lead inevitably to an interplanetary gravity field which is for the most part a geopotential plateau. In close proximity to the planets and their moons, there are gravity wells, which make it difficult to land or take off from the planetary surfaces, but in between these islands it is an easy matter to move about across the interplanetary gravitational plateau using only a minimum of energy. Fig 1 shows the interplanetary gravity field like an elastic sheet, with the various planets' gravity wells as indentations with depths proportional to their masses. We can see from left to right Mercury, Venus, Earth, Mars, then a gap followed by Jupiter and Saturn. We can move out for 10 Astronomical Units and, so long as no landing is planned, very little energy is needed, provided we can get out of Earth's own gravity well to start with.



Credit: Author

Fig 1 Effortless travel across the interplanetary gravity field plateau.

If we look closer at our immediate neighborhood (Fig 2), then it becomes apparent that, while low Earth orbit (LEO), where the International Space Station (ISS) currently operates, does not get us far to the edge of our well, Geostationary orbit is another matter. The Earth/Moon Lagrange Point L1 is even better in this regard, and even the lunar surface itself represents a location that is near the edge of Earth's gravity well. So, in this paper, we are going to propose that we take steps in order to make it a matter of routine to get to the edge of Earth's gravity well, in the sure knowledge that in so doing we shall have made a significant step towards the eventual ability of Earth's occupants in the distant future to head off to a new safer haven for settlement. Meanwhile, of course, we shall see that there are many short and medium term advantages of creating this capability, which need have nothing to do with space settlement.



Credit: Author

Fig 2 Getting to the Edge – The Geostationary orbit is near the rim of Earth's gravity well.

The approach being put forward in this paper is technologically, politically and financially achievable, just so long as the timescale is allowed to develop in accord with certain commercial developments to be described in the next section, and is not artificially shortened into a high-stakes government program. The taxpaying public deserves to have an honest explanation of the very long term background need (centuries or millennia) while understanding the short and medium term benefits from the proposed developments. We are proposing the creation of a "Gateway Earth" station at the edge of Earth's gravity well, and for the purposes of this proposal, and for reasons which will become clear from the subsequent arguments, the location would be in Geostationary orbit.

4. A COMBINED GOVERNMENT/COMMERCIAL APPROACH

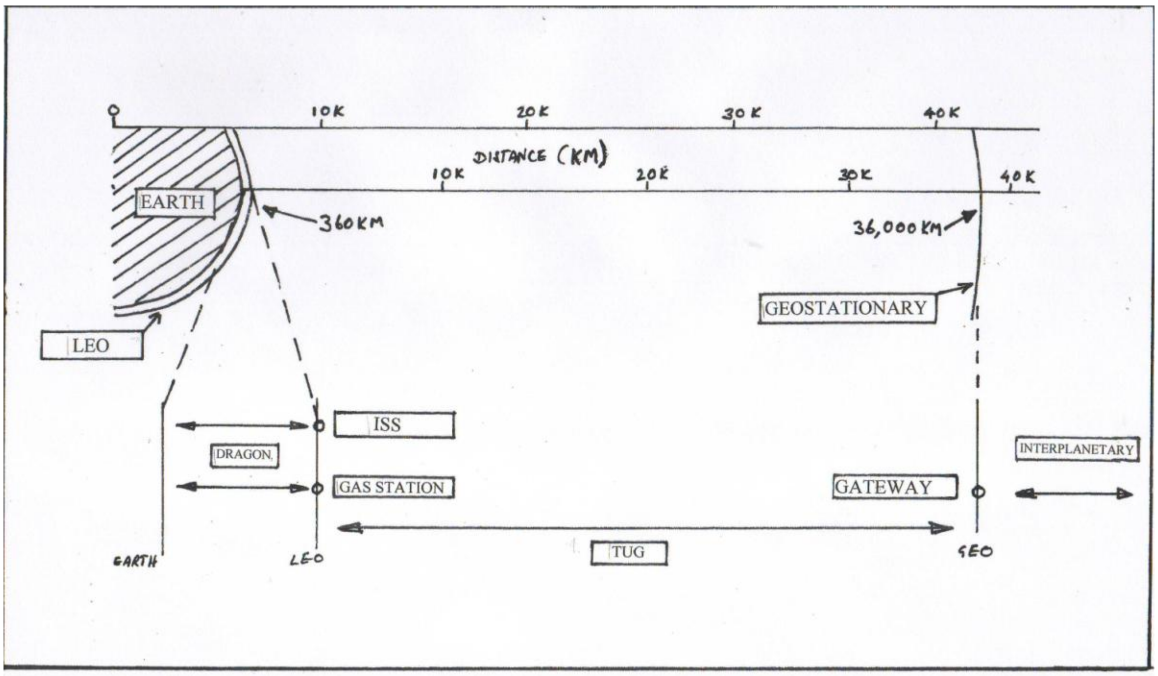
When, under the pressures of a Cold War competition, the US undertook the Apollo program leading to the Moon Landings, it cost the American taxpayers 6% of GDP throughout the decade of the 1960's. Nowadays, NASA's annual budget is roughly one-tenth of that, and in countless opinion polls, citizens have indicated that that is "about right" at 0.6% of GDP. So, with that backdrop, and the associated current international financial crisis, we would be unwise to require any greater government expenditure for space activities. Folks are comfortable with continuing to operate the ISS, and we shall see that that is fortunate, because it is an important node in the proposed architecture leading to the Gateway Earth facility at the edge of Earth's gravity well. Equally, because of financial constraints, it is clearly wise to consider the proposal in this paper as an *international* venture, with contributions from not only the US, but other national space programs. But perhaps even more important than the use of global resources, we shall need to involve *commercial* market–driven space activities to assist in opening up this new Gateway Earth and its regular use.

It is when we consider how to draw upon the parallel efforts of commercial space enterprises that it becomes clear that GEO becomes a better location for the proposed Gateway than either the lunar surface or L1. The associated analysis is provided in Ref 8.3 and 8.4 but in summary, by choosing GEO, despite some problems with that location, it becomes possible to take advantage of two different commercial space activities which will lead to opening up regular operations with Gateway Earth. And therefore, we shall have achieved the advantage of regular flights to the edge of Earth's gravity well, in readiness for whatever interplanetary missions will follow. And we shall have done so, not only without necessarily exceeding current space agency budgets, but in parallel with the creation of two successful commercial space businesses, with their associated employment and tax base advantages. The Gateway (and its supporting delivery infrastructure) thus becomes two parts commercial and one part governmental.

Fig 3 provides an overview of the various proposed architecture elements. The diagram shows the Earth, LEO and GEO orbits to scale, and this underlines how relatively near the Earth is the current ISS operation. The overview makes clear that, if this proposal is adopted, there would be a 3-step approach to interplanetary missions. First of all there is the step from Earth's surface to LEO. Then the step from LEO to the GEO Gateway would require a tug. Thence interplanetary missions can proceed with much reduced fuel needs, using concepts such as a Mars cycler. It also follows that the reverse holds true for return journeys. A spacecraft returning from an interplanetary destination does not need the associated systems for Earth re-entry. It arrives at the Earth Gateway in GEO, and then is transferred to the tug to

LEO, and from there takes the final leg back to Earth. The Gateway itself is needed, and a tug for GEO to LEO transfers. This tug needs to be refuelable, and so there is also a need for an orbiting gas station in LEO.

What are the commercial business elements in this proposal? There are two of them. The first is to have a new destination for space tourism at the Earth Gateway. Tourists would first of all achieve orbit in LEO, and then transfer to the tug for the journey to GEO. There they could observe an entire hemisphere of the Earth. The second commercial market would be the servicing of geostationary satellites.



Credit: Author

Fig 3. Overview of proposed architecture elements

The way in which these commercial and governmental operations would proceed in parallel is described in the next section for each architectural element. But in summary, the proposal amounts to the two commercial businesses effectively "opening up" the routes to the new multi-purpose Gateway Earth, and due to their regular operation providing the means towards reliable and low cost operations. This further implies that the proposed Gateway Earth will need to be a mixed-use facility, with the station being simultaneously a hotel for space tourists, a base for the servicing and refueling of geostationary communications satellites, and a space agency facility where interplanetary craft can be assembled and where returning spacecraft can be guided back to Earth's surface. It would also, of course, be the base for government astronauts for their ongoing science work and explorationary travels across interplanetary space to the Moon, Mars, or wherever. The commercial operators can be expected to provide and operate the LEO/GEO tugs, just as they are soon to begin providing routine service from Earth to LEO, using Dragon, or other spacecraft, under "Commercial Crew" contract to NASA. They would also be expected to provide and operate their modules of the Gateway Earth complex. The space tourism business is already becoming established, but the satellite servicing industry has yet to take place, so this proposal is assuming a possible commercial use which so far has not been developed. Some aspects of these new businesses are addressed in the next section. What can be imagined, however, is that the LEO/GEO tugs would be transporting government astronauts, space tourists, cargoes for the Gateway itself, structural elements of future interplanetary craft intended for assembly at the Gateway, and fuel and spares for failing geostationary satellites.

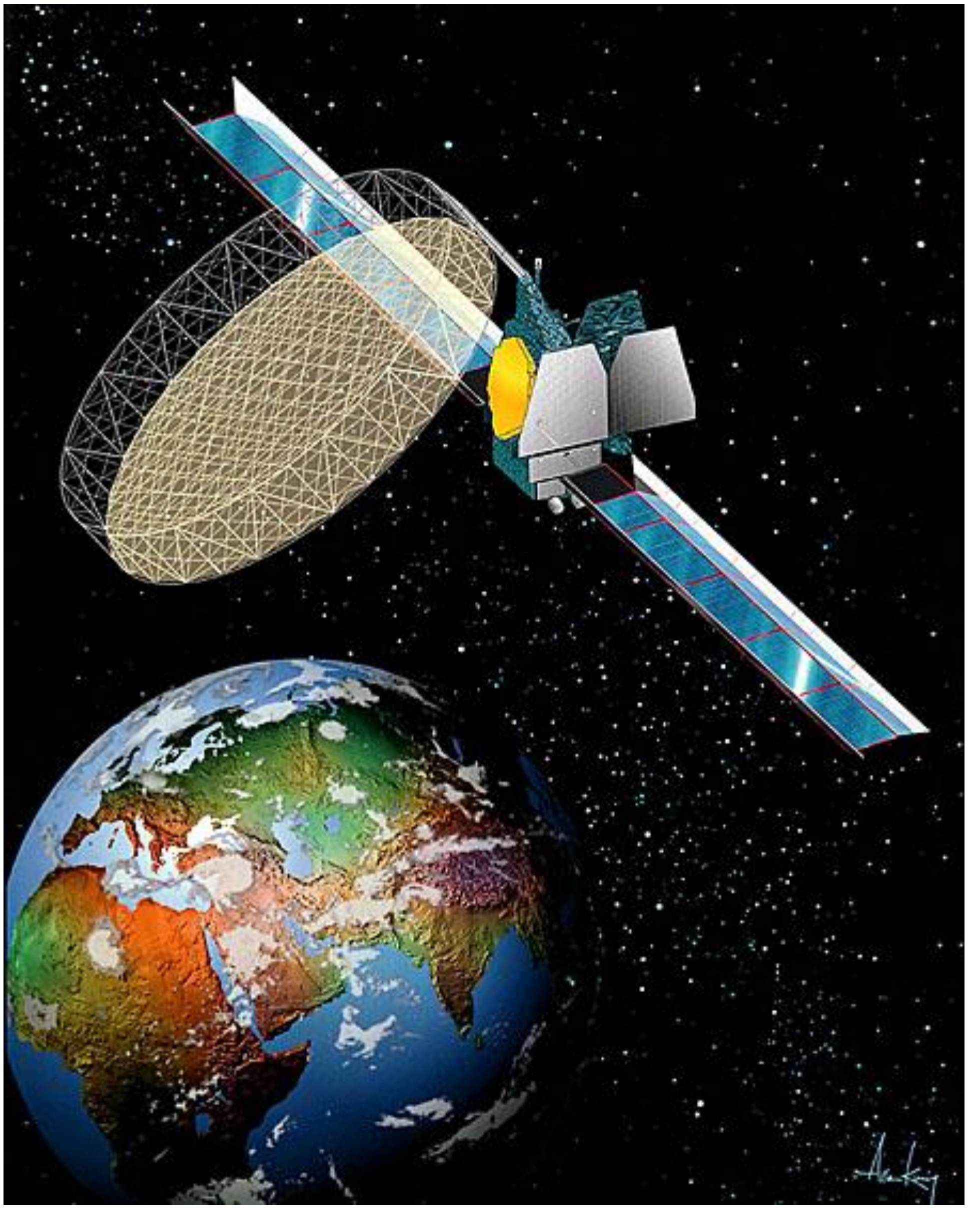
This combined government/commercial approach may succeed provided that the anticipated commercial markets emerge, and that the governmental part of the architecture is implemented on a schedule which allows time for the commercial businesses to develop in parallel. Pragmatically, this implies *a timeframe of around twenty years* before the Gateway Earth complex can become operational. This is because, with regards to the space tourism elements, the companies spearheading this industry need first to recover their investments in sub-orbital space tourism, and then provide a LEO offering, before setting up the new space tourism hotel destination at the Gateway Earth complex. Equally, in the case of the new business of servicing of GEO satellites, there needs to be enough time to create this new industry from scratch. First of all there will need to be a demonstrator which shows how components can be replaced, and fuel supplies can be replenished, while operating in GEO. Then the manufacturers of this kind of satellite bus will need to design and develop a new version which will enable such servicing and fuel replenishment. This could take up to ten years, or twenty years in total, because a newly operating geo comsat might reasonably expect to be able to function for around a decade before needing servicing.

5. ARCHITECTURE ELEMENTS

We have described an overall system which will allow regular transportation to a new Gateway Earth established at the rim of Earth’s gravity well. We have also pointed out that two decades would be a reasonable target timeframe in order for this new proposed architecture to be fulfilled. We shall now address each of the architecture elements in turn, to describe their characteristics as well as can be done at this early stage. It is assumed that the development and manufacturing work on all these elements will take place more or less in parallel over a twenty year period, although some elements will be ready earlier than others.

5.1 Gateway Earth

This will of course be the key end result of all the other associated activity; this will be the space station at the edge of Earth's gravity well. To operate in geostationary orbit will require arrangements and approvals from the ITU, and the US counterpart the FCC. However, there are a few occupancy "gaps" right now, mainly between 144 and 185 degrees west, for which approval might be obtained. Without necessarily knowing what it would look like, we can say already quite a bit about it. It will be something of a hybrid mixture of governmental and commercial parts, for instance. It is quite likely that some of the modules will be inflatable, such as those currently flying as prototypes launched by Bigelow Aerospace. Reference 8.5 points out that already NASA is working with Bigelow to attach an inflatable module to the ISS, so it is reasonable to anticipate that something similar could be the case at Gateway Earth. There will of course be solar array panels for generating power, and Gateway Earth will have three separate functional areas. One will be the space tourism hotel. The second will be the base for the satellite servicing operation. The third will be the governmental space station and assembly workshop. Probably the various entry and exit ports will be located within the governmental section. There will need to be a manipulating arm system to be used in assembly work at the Gateway. In order for the satellite servicing operation to work, the Gateway will need to carry spares and spacecraft station-keeping fuel, and be capable of docking operations with the tug whose duties will involve going around the geostationary orbit and finding and servicing the ailing satellites. The module devoted to the space tourism hotel will require windows and viewing galleries with optical glass, and telescopes mounted for viewing the Earth. Tourists at the hotel will be able to take in an entire hemisphere at a time, (Fig 4), but will require the tourist telescopes to home in on particular regions of interest. At least one astronaut, who has been in this region of space, has advised the author that a telescope is quite satisfactory for viewing purposes.



Credit: Boeing.com

Fig 4 The view from GEO – The Thuraya Telecommunications Satellite

It might be possible to allow journeys around the geostationary orbit using the tug which handles the geostationary satellite servicing. It needs very little fuel to drift around the orbit, and the tourists would thereby be able to see the “other side” of the Earth before returning back to the Gateway. Other features will be developed as a result of experience gained by the early orbital space tourism experience in LEO. As a point of comparison, we may recall that it took around twenty years to design and assemble the current ISS in LEO.

5.2 Tug for GEO/LEO/Satellite Service

This will be a multi-purpose vehicle, probably developed initially with a focus on providing transportation for cargoes and space tourists from LEO up to the GEO Gateway. It will then be extended so that it can also take government astronauts and equipment to the same destination, and yet again so that it can be used to enable the satellite servicing missions in geostationary orbit. A great deal of experience was gained from the Hubble servicing missions about the kinds of on-orbit work that can be carried out when a spacecraft has been designed to allow this activity (as discussed in 5.4 below). The tugs will need to be refuelable and have storage both inside and outside. Items needing to be pressurized will be carried inside, while structural parts would be transported by being attached externally to the tug. The scaling of the tug will require some trade-off work, because it needs to be small enough to enable efficient use by the space tourism industry (capacity maybe 6-8 passengers plus their food, water, oxygen, laundry, etc), while being able to satisfy the needs of the space agencies to allow their astronauts and their equipment to also make the trip. When the tug is in use for the geostationary satellite servicing mission, it needs to carry spare satellite parts and reaction control fuel, and probably a manipulating arm. Furthermore, there needs to be adequate storage (inside and out) for eventually bringing the payloads of entire interplanetary space craft, returning from their mission, back down to LEO, from where they can be transferred back through the atmosphere using the Earth to LEO delivery system. It is expected that a multiple of tugs will be required in order for all aspects of its operations to be fulfilled, and the large potential number of commercial missions will lead to high reliability and a lowering cost of operation. Indeed the management of the traffic flow and cargo delivery system will be an important function of the government part of the Gateway Earth complex. Tugs will probably be built and operated by commercial service providers, and could either be delivered ready-built into LEO, or possibly assembled there alongside the ISS. They do *not*, however, need to be aerodynamic, nor carry any re-entry thermal protection, because they will operate only in the region between LEO and GEO. It is perhaps worth stating here that the commercial space industry has a great deal of experience in design, development and operation of payloads going between LEO and GEO.

5.3 LEO Refueling Station

There have already been experiments to demonstrate the efficacy of in-orbit refueling, and such demonstration missions continue today (see Ref 8.6). Boeing has done a great deal of planning work to make this routine, and so by the time work commences for the LEO refueling station, there will be a good basis of experience. At this stage, we do not need to specify very much about the station, and in fact the key decision of all will be its scale, which will not be known until the trade-offs have been conducted for the whole mission architecture. What should be the fuels stored? How much capacity is needed? Will the whole operation be automatic, or will there need to be human operators, either on the

Earth or in orbit? What kind of rendezvous and docking facilities should be standardized? At what frequency will tugs be returning from GEO to LEO requiring refueling? What will be the delivery system that replenishes the supplies from the Earth? Shall the refueling station also be an intermediate store for cargoes, such as water for the Gateway Earth complex? How shall the interfaces be standardized so that various international operators can have access once the station is operational? In designing the refueling station it will, of course, be important for safety reasons to keep the various tanks and piping separate, and in particular there will be need for special handling for cryogenic fuels. It will take time (one to two decades) and significant amounts of testing, in order to consider all these design decisions and to arrive at a final operating refueling station in LEO.

5.4 New GEO Comsat Busses

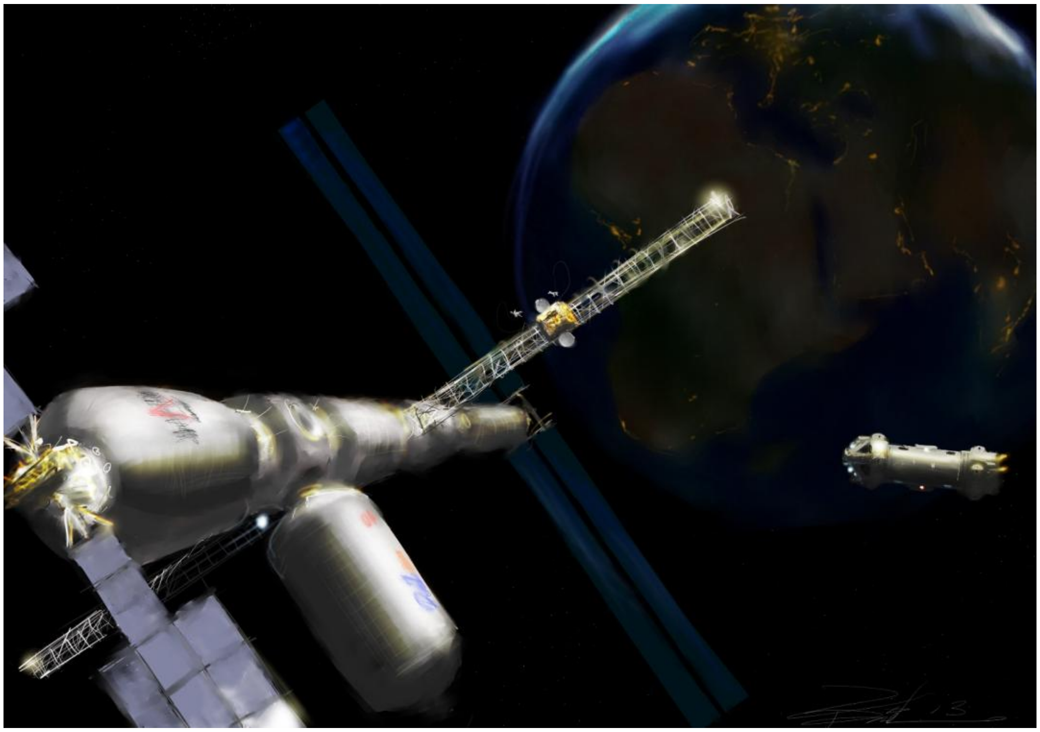
It has already been pointed out above that, in order for the new business of geostationary satellite servicing to be possible, a major rethink will be required in the design of commercial comsats. In general, geostationary communication satellites consist of two parts, the communications payload – which differs for each customer – and the spacecraft bus which tends to be standardized. It will be necessary to develop new designs of spacecraft buses at each of the spacecraft manufacturers, in order that refueling will be possible, and that certain vulnerable units may be replaceable in orbit (as was demonstrated with the Hubble space telescope). Certain kinds of fittings will become standardized when these design changes begin to be introduced. It should be stressed that the buying and selling of geostationary communications satellites is a well established commercial business, and so there will have to be a demonstrable commercial benefit to both the manufacturer and the operator for these changes to be agreed. The way in which these negotiations may take place is not a subject for this paper, but we can at least understand various aspects of the trade off. The manufacturer has a successful and tried and tested bus, which due to the operation of a competitive marketplace, the operators have been able to obtain for a commercially acceptable price. The necessary changes to allow on-orbit servicing will introduce risk, increase the capital cost, and cause delay, while offering potential benefits in longevity near the end of what is normally a ten plus years lifespan. The possible future successful availability of the geostationary servicing business, and its costs, will not be known for certain at the time these decisions are being taken, and at the time that contract commitments are being undertaken for purchases of the new on-orbit service-enabled communications satellites. The well-established satellite insurance industry will also be involved in the discussions and negotiations about whether or not the spacecraft designs will be changed to allow for in-orbit retrofitting and refueling. That's a whole lot to do – which is why we assume it takes at least a decade before the first of the new satellites is launched, and then we need to allow maybe ten more years for the first failures to occur requiring a servicing mission.

5.5 Commercial Crew

The final element to enable this architecture for survival to be undertaken is fortunately almost already available. NASA has in operation a "Commercial Crew" program, whose purpose was to replace the Space Shuttles in their ability to bring cargo and people to the ISS in LEO, and to return them safely to Earth. Various manufacturers are working to provide the necessary spacecraft and the current phase of this program is called CCiCap. SpaceX is providing the Dragon launched on Falcon 9, and has already demonstrated the ability to deliver cargo to the ISS using this combination, so it is included in Fig 3 as the provider of the Earth to LEO service. Boeing, however, is also developing a launch vehicle/spacecraft combination, CST 100, to offer the same functionality. There are other potential providers, including Sierra Nevada with Dream Chaser, Blue Origin and Orbital Sciences with Cygnus. At least one of these commercial options will eventually be delivering passengers (including tourists) as well as cargo, to LEO.

5.6 Integration

One of the hardest aspects of this proposal to implement will be the fact that it depends on the combined activities of both governmental and commercial entities. This will make the scheduling particularly difficult, since the commercial parts will not come together until the business case has been proven sufficiently to raise the financing. This means that it will not necessarily come together tidily and simultaneously. Perhaps a single tug might operate for several years before more are added. Perhaps the space hotel part of Gateway Earth will be operating for several years before the satellite servicing module arrives. Perhaps NASA and/or other national space agencies will have budget difficulties which delay the government part of the complex. Nevertheless, we can imagine a time when all the parts are in place and operational, and that time is captured by the image in Fig 5. We can see the complex in geostationary orbit, composed of its three different sections, and being visited by one of the refuelable tugs. Some astronauts are conducting EVA activities in support of the government part of the Gateway.



Artist credit: Phil Smith

Fig 5 Gateway Earth with an Arriving Tug.

6. IMPLEMENTATION

We have laid out the proposed architecture, and considered each element in isolation, but we cannot deny that it would be a major management challenge to bring the whole operation to a successful conclusion. That is because the proposal is not for a monolithic program under the control of a single government entity (as was the case during Apollo, for example). This proposal is very much harder to manage, partly because it could require the cooperation of many national agencies (and we know from the ISS that such an approach is achievable, but difficult and frustrating). But it will be harder in particular because certain key elements of the proposal will not be under any government control at all. They are the commercial elements, whose existence, and timescale, will depend on the vagaries of the market place. First of all, we need to await a successful space tourism business in the sub-orbital regime, and in LEO, before we can expect the necessary investments for a GEO phase of the business. With regard to the geostationary satellite servicing business elements, again we will have no central control of developments. There needs to be time for potential service providers to have discussions and negotiations with all the involved parties before any decision could be made to attempt to create that business.

But, even though it will be difficult, let's not forget that it is *because* of the possibility of these two commercial businesses being established and successful that we can even consider the proposal for a Gateway Earth at the edge of Earth's gravity well *at all*. In other words, this is a paradigm shift in the way advancements in space can take place. We are beginning to implement a phase of space exploration, and eventually space settlement, enabled by the traditional commercial and economic development engines which made the US so successful in the first place. And this will require a different kind of manager from the previous skill sets available in the space agencies. Not impossible, but recognizably different. It has worked, for example, quite successfully in the communications satellite business, and it looks destined to be able to repeat the trick with the new space tourism sector. Space is becoming just another part of the array of commercial businesses which form part of the overall Standard Industrial Classification. Which is just as well, because governmental funding of this sector has reached its limits, and only by using the commercial entrepreneurial sector to build and operate the backbone services can we make progress. At least, that has been the assumption in this paper.

We can make an initial essay into the implementation process. A number of different things need to be done in parallel over the first year or two. The national space agencies need to agree that a Gateway Earth with its associate logistical supply system makes sense. Preliminary discussions will be needed with the ITU to consider any potential regulatory hurdles, and to reserve the slot for the Gateway. The space tourism sector needs to begin to consider whether there would be a market for a visit to Gateway Earth, and how much it would cost – they will need to conduct some new market research amongst wealthy individuals. Representatives of the satcom industry and its associated insurers need to discuss the pros and cons of designing a new class of serviceable geostationary satellite. If there is a positive consensus, then someone must commence the new satellite servicing business, raise the capital, and ensure that the necessary design and testing takes place for the servicing vehicle, including its docking mechanisms. The satellite service operators can then start to include a servicing/refueling capability in the tech specs for the next generation of comsats, and the manufacturers can begin to explore how they can achieve this capability, and what it will cost. Boeing, and other manufacturers who have been exploring on-orbit refueling, will need to conduct more experiments to demonstrate that a refuelable tug is a possibility, then proceed to designing and building the first in-orbit LEO gas station.

After this first phase is over, and there is agreement about the overall plan, and the kinds of interfaces which need to be standardized, then the design and testing of the tug can take place – perhaps initially as a space tourist transfer vehicle. The detailed design of the Gateway station itself can then be agreed. Note, however, that it should be modular and therefore flexible, so that there is no need for exhaustive "optimization" design stages as was the case with the ISS. Initially, for example, it might consist of a single Bigelow module. Some of the funding will be governmental; some would be commercial.

In the background, and throughout this two-decade period, the national space agencies, such as NASA, will need to be conducting the kinds of fundamental

R&D work needed to make this proposal possible, using funding in the usual governmental budget cycle. They can be expected to fund the experiments in on-orbit refueling, for example, and they can begin to explore the design possibilities for the new craft that will ultimately be assembled, and sent on interplanetary trajectories, from their new starting point, Gateway Earth.

7. CONCLUSION

We are proposing a new architecture for space development which should be fundable without additional annual budget requirements than is the case today. The plan would probably take twenty years or more, however, in order that these funding levels be achievable - and what is more perplexing, it will be uncertain in its schedule (because an important part relies on the gradual implementation of commercial businesses). What would result is a multi-use Gateway space station at the edge of Earth's gravity well, with a logistical system providing the regular transport to and from the new Gateway, and employing new technologies such as in-orbit fueling.

The Gateway Earth would have commercial and governmental uses, and therefore the funding would be a combination of commercial and governmental funding. In following the proposal, a new business, with associated employment opportunities, will be created to provide for servicing of satellites in the geostationary orbit, thus making satcoms a more efficient business in the long term. The Gateway would also provide for a new location for an expanding space tourism industry. By using the new class of space tug vehicles, built and operated by the space tourism operators, space agencies will be able to send their astronauts to Gateway Earth, where they will be able to assemble new generations of interplanetary vehicles for subsequent exploration missions across the solar system.

We have seen that implementation of this proposal will require a new kind of management of space projects; one that is perhaps more akin to the management of a satellite telecommunications operator than to a traditional space agency. If implemented, this proposal would provide an excellent bridgehead for all future developments requiring interplanetary travel. We would have secured our ability to regularly and at relatively low cost reach the edge of Earth's gravity well. We would have created the firm basis of an architecture for survival for future generations to use.

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