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China's Space Programme - Hare or Tortoise?

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Abstract

The 21st century is believed to become the Asian century. In the last few years China has introduced several economic and political initiatives which promote its rise as a global power. Embedded in its development and rise is the national space programme. This allows the country to follow a very smart concept for the space programme. The basic principle is to develop 'key systems' such as launch sites, launchers or TT&C systems which can be used across the different fields of space exploration: from Earth observation to the manned space programme, lunar exploration or other programmes. It is maybe a little bit like a Lego system or the menu of a Chinese restaurant. Western observers tend to look at China's space programme as being small, slow, technologically less advanced and not significant enough. Is that correctly reflected or what is it then? Is China's space programme the hare or the tortoise? Is it possible to predict China's near-term future in space? The authors have consulted open sources and performed in-depth analyses to find qualified answers to those questions. The first part of the paper looks into the historical context of China's space programme, while the second part tries to shed light on the current developments.

1. Preface

Exploration by mankind has never been limited to physical excursions only. While men and women will reach as far as their feet will carry them, the most powerful means of exploration is humanities unique capability to explore with its mind, imagination, heart and soul. Where their feet are not able to carry him or her, the mind will be able to take them anywhere. This may be the reason why most if not all cultures on our planet know legends, fables, and fairy tales connected with the universe: the man or the woman in the Moon, the jade rabbit accompanying the Moon princess Chang'e, the endlessly diverse interpretations of the stellar constellations, and yes, the naming of the planets in our solar system - all connect mankind with its ancient heritage of the origin of the world. Fairy tales are always helpful to illustrate sober technical or scientific facts. This may be the reason why for the last decade the Chinese space programme, has often been referred to the fable of the 'hare and the tortoise', just for the purpose of asking the question of what China's space programme really is about.

2. Hare or Tortoise

Just for a quick recapitulation: Once upon a time the proud and idle hare was observing day-by-day the little tortoise patiently and enduringly going on its way at a slow and somehow tiring to watch pace. The hare did not spare to mockingly comment on this art of moving until the tortoise had enough of this and said: "Only because you have such long legs you must not think you can always be the fastest." To which the hare replied: "Let's have a competition and I will show you that I am always the fastest hare in the world." The tortoise agreed and they started the race. Once the hare reached the river and he saw the tortoise was far behind, he decided to lay down against a tree for a short rest. When the tortoise reached the hare he was fast asleep and the tortoise, focussed and dedicated, continued on his way until he reached the finish line. The hare in the meanwhile was still sleeping…

In similarity with this fable, China's space programme is looked at as being a tortoise: small, slow, irrelevant. And indeed, when it comes to budget, the money China invests in space is a relatively small amount; an estimated 1/10 of NASA's budget which translates to

approximately 1,8 billion US$ versus almost 20 billion US$ for NASA's annual household.
Likewise, China's space programme is considered to be slow. Looking at the past and current situation this impression is not completely wrong since there have not been that many missions. For example, in the human space programme, so far only 5 manned missions with 10 taikonauts involved (2 taikonauts flew twice) have been completed since 2003.
Also, critics point out that China is technologically behind, still far behind the technologically most advanced countries. In particular in the space sector, China has been living off copied Soviet-Russian technology.
With no significant science missions so far - what is the core and strength of NASA (National Aeronautics and Space Administration) and ESA's (European Space Agency) efforts - China is often not accepted as a major space nation. And anyway, it is said that China is primarily aiming for military objectives, namely dominance in space.
So what is it then? Is China's space programme a dynamic hare or a laboriously moving tortoise? Is it a threat to the world?

PART 1 - HISTORY

3. Milestones of China's recent societal and economic development

The birth of national space programmes all over the world have always been embedded into the societal context of the (respective) time. To understand China's space programme it is necessary to keep in mind a few, but highly relevant milestones in the societal and economic development of the country, in particular after World War II until the turn of the millennium. At a time when in Europe, Japan and the U.S.A., crucial economic development took place, the Chinese economy rode on a rollercoaster. (Fig. 1) The time period after the founding of the People's Republic of China in 1949 until 1958 was marked by a moderate economic growth. Initiated in 1958, 'The Great Leap Forward' project was supposed to catapult China within 15 years into the league of leading industrial nations. After only 3 years however, the economy of the country was broken. The following Five-Year-Plan brought some relief, until in 1966 the 'Great Proletarian Cultural Revolution' took its course. The persecution of intellectuals and academics damaged a whole generation of experts, teachers, the scientific elite – most of China's best talent. The economy during the 'Cultural Revolution' did not completely stand still, but progress did. Only after the death of Mao Zedong the situation could halt. China's firsts in space are embedded into these dramatic decades of the nation's post-war development.

Milestones of societal development in China
1945: end of World War II
1 October 1949: Founding of the People's Republic of China
1950 - 1953: Korean War
1958 - 1961: The Great Leap Forward
1966 - 1976: Great Proletarian Cultural Revolution
1977: Deng Xiaoping – Opening Up and Modernisation
as of 1990er: new orientation in economy, society, development

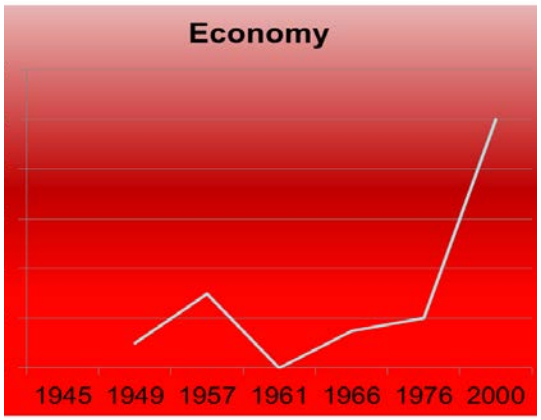

Figure 1: China's economic development as a rough visualisation (not based on real figures – for illustrative purpose only).

4. Firsts in space

4.1 The East is red – Dong Fang Hong (DFH 1)
China's space programme was not driven by a race, as compared for example to the space race between the U.S.A. and the Soviet Union. For China, the underlying principle was to catch up with leading technology developments in the world and to become a respected member of the international community, preferably the most advanced nations. Also, the development of China's space programme has something to do with letters written to the government, the decisions of far-sighted persons … and strangely: initially a preference for shopping rather than for developing.

As an outcome of the Korean War, China felt under nuclear threat and asked the Soviet Union for technical assistance in the development of its own nuclear capabilities including long-range missiles. The Chinese request was granted. The launch of Sputnik 1 on 4 October 1957 by the Soviet Union sincerely impressed

the 'Great Helmsman', Mao Zedong. Such a satellite he wanted to have for his own nation. [1]
The Chinese Academy of Sciences (CAS) set-up a task force for the technical and scientific development of an indigenous satellite connected to a long-term and comprehensive national satellite programme. CAS was fully aware of the relevance of satellites for future national scientific and technical development.
Meanwhile, the 'Great Leap Forward' was initiated, and despite support by Deng Xiaoping, by that time Secretary General of the Communist Party of China, too few allocated resources, material, and work force made it impossible for CAS to succeed with a national satellite. The Soviet Union gave no support to China in the civil space sector. Lack of progress and missing know-how made the Chinese experts realise that they had to start from scratch: developing sounding rockets first. And they did.

After the 'Great Leap Forward', the Chinese leadership focussed on the so-called 'Four Modernisations', among which was also science and technology. The satellite work group within the CAS was still struggling. The Director of CAS's Geophysical Institute saw the big progress the military made with the development of missiles and wrote a letter to the party leaders in which he suggested to "combine the tests of our ballistic missile programme with launching a satellite, and get the benefit of hitting two birds with one stone." [1]

In 1966 the 'Cultural Revolution' deeply impacted the Chinese society and shook its foundations. Intellectuals were targeted and scientific institutions became places of conflict and violence. Under those circumstances, CAS and other institutions involved in space developments asked the Communist Party to protect their institutions with the help of the military. Mao approved and since that moment the Chinese space programme and the People's Liberation Army were tied together and have remained in tandem until today.

After 12 years of hard work, impacted by economic and technical constraints and political and societal interference, China launched its first satellite DFH 1 on 24 April 1970 (in the middle of the chaos of the 'Cultural Revolution'). China thus became the fifth nation in the world to do so. The singing satellite was more of a propaganda instrument than the starting point for a solid, sustainable science programme. However it flew and was sending signals.

China's second civilian satellite launched in 1975, carrying some of the payloads originally intended for DFH 1.
Although most Chinese satellites until today are based on the DFH bus, the actual intention of the scientists and engineers to aim for a long-term programme only began to evolve in the 1990s.

Looking at those developments of the past, gives any observer, indeed, reason to think of the Chinese space programme as a slow tortoise.

4.2 GEO-Satellite
The history of China's first geostationary satellite is no less interesting. The initial spark to go for GEO (geostationary orbit) came from a letter written in 1974 by telegraph workers to the government. [for details: 1] Those concerned telecommunication specialists pointed out to the Chinese leaders that positions in geostationary orbit can only be assured by actually placing an object there.
This letter triggered China to finally notify the International Telecommunication Union (ITU) that they intended to place a satellite into GEO by 1980. In 1976 the 'Cultural Revolution' came to an end. The rising political cadre became Deng Xiaoping who was by that time responsible for education, science, and technology – one of the four 'modernisations' that he thought to be the most important.
Deng became famous in illustrating his idea in a 1978 meeting when he tried to persuade his comrades to go for a communications satellite programme in this enthusiastic way: "If we invite a good teacher to give a lecture in the Great Hall of the People only 10,000 people can hear it, but if the same teacher were to give that lecture on television, and everyone had the equipment to receive it, that's a classroom of unlimited size." [1]

Deng Xiaoping succeeded and the GEO satellite programme went through. Ambitiously, it was also decided to develop a cryogenic upper stage, which led to a delay in the overall programme. At a certain point Deng wanted to buy a communications satellite from the U.S.A., however this initiative did not work out and the self-set deadline for a launch in 1980 was slipping. In a way – as before with the Soviet Union – the insight prevailed that instead of relying on support from other countries, China has to find and go its own way. Also, Deng was quoted as saying that China can buy one, two, three satellites, but at the end of the day, a big nation such as China cannot buy satellites forever if the

country wants to make critical technological advancements. [1]

In the second half of 1983 China accomplished the five major systems needed: launch vehicle, satellite, launch site, the tracking and telemetry equipment, and a network of ground stations.
On 29 January 1984 the first launch failed because of problems with the cryogenic upper stage. In a flexible move, China declared the satellite an 'experimental satellite'. The second attempt on 8 April 1984 was more or less successful. China launched its GEO satellite. Problems with overheating batteries were solved by adjusting the satellite's attitude so that less sunlight would hit the solar cells and consequently recharging the batteries just enough to keep the satellite in good working condition. Although this shows a creative and flexible problem-solving attitude by the Chinese engineers, it took China 10 years to become the 5th geostationary nation in the world. Again, thinking of a tortoise rather than of a hare might make sense.

4.3 Human Spaceflight
The most effort and trouble caused the initiation of the human space flight programme to China.
Back in 1966, a feasibility study investigated the option to use synergies from the first satellite programme for a human spaceflight programme. 1970 – in the middle of the 'Cultural Revolution' – the so-called 'Project 714' was approved. It aimed at launching a Chinese astronaut in space by the end of 1973. Taikonaut candidates were selected and sent to Star City, near Moscow, for training with the Soviet experts. It was Mao himself who disbanded the astronaut corps again: "We should take care of affairs here on Earth first, and deal with extraterrestrial matters a little later." [1]
Maybe a bit of a surprise is the fact that the person who later officially cancelled China's human space flight effort was Deng Xiaoping. In 1976, shortly after the end of the political chaos of the 'Cultural Revolution', Deng declared that China "should not participate in the space race" and instead we should "focus our energies on urgently needed practical satellite applications": the recoverable/GEO satellite programmes. Deng Xiaoping who was responsible for space had more interest in space applications and since he was not sure whether the resources were sufficient for everything, he wanted to set priorities.

However, the SDI speech from 23 March 1983 by U.S. President Ronald Reagan, led to discussions in China on what the role of science and technology is for a country's national development. Again, a letter was written. In the beginning of 1986, 4 senior scientists wrote to Deng Xiaoping, pointing out that China needs to make concentrated efforts in the area of technology and technological breakthroughs.

In April 1986, the legendary document: 'An Outline for National High Technology Planning', the 'Plan 863' was published and in October of the same year, the plan was approved and budget allocated. As before, the goal of the Chinese human spaceflight programme was not to race with, or surpass other nations, but rather to stop the process of falling too far behind. China was in need of an ambitious project that would develop a national space industrial infrastructure and promote the education of the needed talent and specialists.

Key objectives of Project 863:
- study and analyse international trends in science and technology
- sustainable scientific and technical know-how needs its own development with long-term commitment
- it takes a large and attractive project to inspire, organise and train the necessary human resources

The next five years were marked by a debate over serious differences on the fact whether China should go for a space shuttle design or the space capsule technology, causing the delay of 'Plan 863' for more than five years. [more details in: 1]
Finally, the Standing Committee of the Politburo approved the space station plan on 21 September 1992, declaring the Chinese Space Station (CSS) the core of China's human space flight efforts.

Despite lessons from the past, in the mid-1990s, China considered purchasing a complete Soyuz spacecraft from Russia. After lengthy negotiations, the Chinese scientists and engineers only "got bits and pieces, here and there" from their Russian counterparts and, in the end, "had to do the bulk of the work themselves." [1]

Although the launch vehicle, the Long March 2F (LM-2F), was ready in time, the Shenzhou capsule was behind schedule and alternative payloads were considered.
Only on the 20 November 1999, Shenzhou 1 lifted off from the Jiuquan Satellite Launch Center in the Gobi desert for a successful unmanned mission. Three more unmanned test flights would follow.

Interestingly, the systems on the last unmanned mission, the Shenzhou 4 flight, were equipped to support a mission with two taikonauts who would spend three days in space.

Global events like the 2003 Space Shuttle Columbia disaster and the problems with the Russian Soyuz capsule ballistic re-entry after undocking from the International Space Station but also events at home, like the SARS epidemics which impacted every aspect of life in China's major cities, also had consequences for China's first human mission into space. The flight of Yang Liwei with Shenzhou 5 on 15 October 2003 was a one-crew mission that lasted 21 hours and made China the third country in the world capable of human space flight.

For more details on these historical aspects of China's first steps into space, it is highly recommended to study the paper by Gregory Kulacki and Jeffrey G. Lewis 'A Place for One's Mat: China's Space Program, 1956-2003' [1]

Despite the gigantic success of accomplishing a human mission into space, the following years saw just four more human space flight missions conducted by China. The firework display of manned flights, as the world has seen at the beginning of the Soviet Union or U.S.A. space programmes, was not repeated by China. Looking at this from the outside, the image of the slow tortoise remains persistent.

PART 2 - TODAY

5. Caesura – The Economic Boom

The economic success at the turn of the millennium was a kind of change in the way things were done: The Middle Kingdom felt confident to go for bold visions. This time of the economic boom not only provided China with the self-confidence and self-esteem to proffer big societal concepts, but was also the point in time to give science, technology - and with it space - a fundamental new orientation and direction to meet the needs of the future of the nation.

5.1 White Papers

Since 2001, in parallel with the respective five-year plans, China has issued its 'White Papers on Space Activities'. So far 3 have been published, the 4th is expected this year as an accompaniment to the current 13th five-year plan. The main purpose of the "White Papers" was to summarise the achievements of the past and to explain the objectives and the work to be done in the area of space for the coming five years.

The overall structure of the papers throughout this period has remained the same. i.e.:

I. Stating the principles and strategy behind the paper.
II. Summarising the current status and major events that occurred during the previous five years.
III. A review of the planning for the upcoming five years.
IV. A statement of the policies and measures defined to ensure completion of the goals and tasks.
V. The status of China's cooperation at international level.

The most important take away from the 'White Paper' could be that China views the space domain as a critical strategic element:
"The Chinese government has all along regarded the space industry as an integral part of the state's comprehensive development strategy, and upheld that the exploration and utilization of outer space should be for peaceful purposes and benefit the whole of mankind. As a developing country, China's fundamental tasks are developing its economy and continuously pushing forward its modernization drive." [5a]
The reader meets again objectives from the 'Project 863' aiming at attractive programmes in favour of the country's space industrial base, for the development of new generations of talented people and multi-function and multi-orbit space infrastructure. However, it is complemented with the objective of strengthening innovation capacities and commercial applications.

There is a strong commitment by China to build its strategy on a foundation of clearly-defined key principles. The principles form a common silken thread running through all of the 'White Papers':

1. Maintain and serve the country's overall development strategy.
2. Uphold the policy of independence and self-reliance.
3. Maintain comprehensive, coordinated and sustainable development.
4. Adherence to the policy of opening up to the outside world.

Also remarkable is that the strategy at the highest-level remains consistent, i.e. incremental progress is achieved step-by-step. (such as: 'steady growth and consolidation' reaching nine types of satellites (including Beidou); expansion of their TT&C

capabilities (ground-based, space-based, ships, deep-space). No giant leaps!

At the lower level, the prioritisation of the various space activities does change, in response to internal or external events, but the overall direction is maintained. China's strategy has three major characteristics; consistency, consistency and consistency.

China is more than willing, indeed actively seeking, international cooperation. It bases its cooperation around the principle of 'win-win' and long-term stability.

A final observation relates to China's modesty. Despite all of the considerable achievements, in general, but specifically in the space domain, China continues to refer to itself as a 'developing country'. This attitude might drive China to more and more success in the long-term, leaving room for comprehensive improvements and giving way for learning and openness.

5.2 Roadmap 2050

In mid-2009, the 120-page document 'Space Science & Technology in China: A Roadmap to 2050' was published by the CAS and one year later in English.

The 'Roadmap 2050' analysed the flaws and strengths of China's science community, the worldwide trends in space and technology, and came up with long-term and far-sighted goals and steps in achieving them.

China's political and academic elites realised that the country was in need of a strategic, long-term approach and answers to questions such as:
"What will be the whole plan for China's space technology?
What is the objective?
Will it just follow the previous approach of developed countries?
Will the traditional chemical fuel propellant still be used in future deep-space exploration?" [7]

The roadmap activity was initiated, aimed at predicting the future developments of science and technology in accordance with the needs of the Chinese nation for the next 20-30 years "to address the needs of both, the nation and society, the continued growth of economy and national competitiveness, the development of social harmony, and the sustainability between man and nature." [7]

Science, technology, innovation and management have to be interconnected with the economic societal base. Space has to become a tool for the benefit of Chinese society, and the achievement of the overarching goals and synergistic efforts as laid out in the roadmap. An analysis of the recent history of science and economy brought to light that the growth by purely extending economic production has reached its limit.
China's future economic and social development will largely depend on science and technology through scientific discoveries, through the realisation of so-called 'Mega Projects', and through new inventions and technological innovation. This holistic approach is the strength of the document: it includes not only the science and technology of relevance for the future, but also the respective roadmap to meet the objectives, a description of environmental changes, research needs, technology trends and developments in innovation as well as technology.
"The past 250 years' industrialisation has resulted in the modernization and better-off life of less than 1 billion people, predominantly in Europe, North America, Japan and Singapore. The next 50 years' modernization drive will definitely lead to a better-off life for 2-3 billion people, including over 1 billion Chinese, doubling or tripling the economic increase over that of the past 250 years." [7]

The 'Roadmap 2050' outlines as a strategic objective for **space science**: making significant contributions to human civilisation; for **space technology**: providing strong support for science exploration and space information applications and for **space applications**: being an indispensable support for national decision-making.

In the 'General Roadmap 2050' the step-wise implementation of China's strategic space aims is shown and it maps technologies against space science as well as technologies and science against applications. These general maps illustrate where breakthroughs in the development of space technologies are necessary to achieve certain exploration goals. For example, it lists which steps and which technologies, and which applications are needed to achieve a certain step in the roadmap. For the extension of human exploration beyond the Earth's orbit, first capabilities in autonomous navigation and positioning are indispensable. For the robotic exploration of the Moon, some breakthroughs are required, while for a robotic Mars landing, systematic technological breakthroughs in deep-space exploration, autonomous navigation and

positioning become a precondition. For a manned lunar landing or even manned exploration towards Mars, capabilities on the most advanced level in the world are a prerequisite.

In addition to the 'General Science Roadmap 2050', sub-roadmaps for space science, related space technologies, and space applications were designed. Those sub-roadmaps include timetables of the necessary missions to reach the respective strategic goal. For example, in the sub-roadmap space science for the strategic goal "Exploration of the Solar System" the following steps were listed:

- 2012: first lunar soft landing and surface exploration
- 2017: first lunar sample return
- 2020: launch of planetary science laboratory
- 2025: probe landing on and exploration of Mars
- 2030: first manned lunar landing
- 2033: first Mars sample return
- 2040: construction of first short-term manned lunar base
- 2050: first Mars landing

This list shows that the plan for manned lunar and Mars exploration is clearly in the mind of China's space experts. However, important in China is, that at the end, the political leadership needs to allocate budget and resources. This happens according to the economic Five-Year-Plans. Whether or not China will make it to the Moon (already achieved robotically) or Mars will very much depend on the fruitful interaction between economic, scientific and societal growth and prosperity.

Principles of Chinese Space activities

China carries out its space activities in accordance with the following principles:

1. Adhering to the principle of **long-term, stable and sustainable development** and making the development of space activities cater to and serve the state's comprehensive development strategy. The Chinese government attaches great importance to the significant role of space activities in **implementing the strategy of revitalising the country with science and education and that of sustainable development, as well as in economic construction, national security, science and technology development and social progress. Space activities are encouraged and supported by the government;**
2. Upholding the principle of **independence, self-reliance and self-renovation** and actively promoting **international exchanges and cooperation**. China relies on its own strength to tackle key problems and make breakthroughs in space technology. Meanwhile, it gives attention to international cooperation and exchanges in the field of space technology. Self-renovation in space technology is combined organically with technology imports on the principles of mutual benefit and reciprocity;
3. Selecting a limited number of targets and making breakthroughs in key areas according to the national situation and strength. China carries out its space activities for the purpose of satisfying the fundamental demands of its modernisation drive. China **selects a limited number of projects that are of vital significance to the national economy and social development**;
4. Enhancing the social and economic returns of space activities and paying attention to the **motivation of technological progress**. China strives to explore a more economical and efficient development road for its space activities so as to achieve the integration of technological advance and economic rationality;
5. Sticking to **integrated planning** by combining long-term development and short-term development, combining spacecraft and ground equipment, and coordinating development of space technology, application and science.

[8] ISU SSP03 Tracks to Space – Report http://ice.sso.esa.int/intranet/communities/Technology Observatory/TRACKS_to_SPACE_Report.pdf

6. LEO – Efficiency is key

Is there a specific reason why the Chinese space programme seems to be on a slower pace as compared to the initial years of the leading space nations the Soviet Union and U.S.A.?
Looking at current projects might shed some light on the underlying principles of how Chinese engineers, scientists and project managers approach space.

6.1 Shenzhou

China started its manned mission with Shenzhou 5 and a one-person-crew in 2003. Followed relatively quickly by Shenzhou 6 with a two-member crew two years later, and again two years later in 2008 the three-member

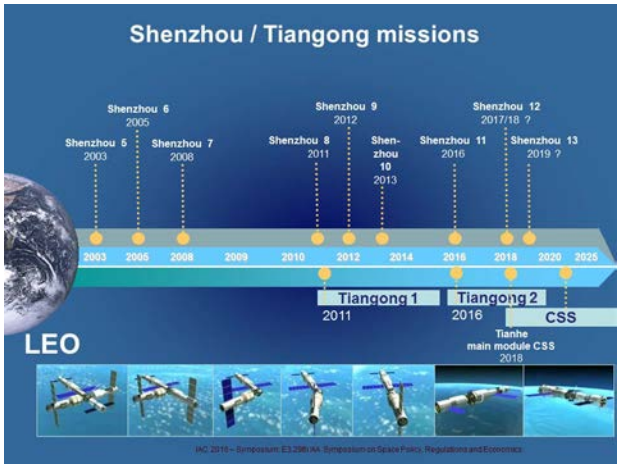

Figure 2: Time line of Shenzhou and Tiangong missions.

crew on Shenzhou 7 successfully conducted China's first EVA. It seemed that China took a break to analyse, learn and adapt before launching in 2011 the next Shenzhou mission, an automatic docking with the already in orbit Tiangong 1 space module. Shenzhou 9 docked with a three-person crew in 2012 sending China's first woman into space. And again one year later, in 2013, Shenzhou 10 delivered three taikonauts to Tiangong 1. Female crew-member Wang Yaping succeeded in fulfilling Deng Xiaoping's vision of a classroom of unlimited size when she delivered a lesson to 60 million Chinese students from space.
After that group of missions, again there is a break. We are expecting that the second space laboratory Tiangong 2 will soon be placed in orbit to welcome space crews. It should sound plausible that China used the time in between Tiangong 1 and Tiangong 2 to analyse, learn and adapt before starting again with its next cluster of space missions. (Fig. 2) This specific cluster behaviour which we have seen in the human space flight programme might be the preferred mission conduct for China because it gives the nation's experts the best possible chances to learn and improve. Also, the low number of missions is a specific Chinese characteristic. There is no waste of resources – missions are done for a purpose, a justified purpose. A fact we have seen also with the operation of the space laboratory Tiangong 1.

6.2 Tiangong

The Tiangong 1 space laboratory is a man-tended mini space station based on Shenzhou technologies, consisting of an improved Shenzhou propulsion section and a newly developed, larger pressurised section. It was launched in 2011 and was for 4 1/2 years in good working condition (with a loss of operations in March 2016). Tiangong 1 acted as a docking target and in contrast to initial, less advanced, plans, it did have a life support system and other sub-systems capable of supporting manned occupation. Tiangong 2 is planned for the 3rd quarter of 2016 to host crewed medium-term stays. It will be fully functional, and will be used mainly for space scientific experiments.

Initially, Tiangong 3 was planned as a test-bed for the future permanently man-occupied modular space station. However, efficient use of Tiangong 1 has made Tiangong 3 redundant.

The future Chinese Space Station (CSS) is designed as a Mir-class orbital complex which, in full contrast to the International Space Station (ISS), can be operated and maintained within national space flight capacities.

It seems that China has proven with its human space flight efforts that the image of the slow moving tortoise is becoming obsolete. It is neither a hare however, as speed is compensated with efficiency.

6.3 Efficiency in Chinese

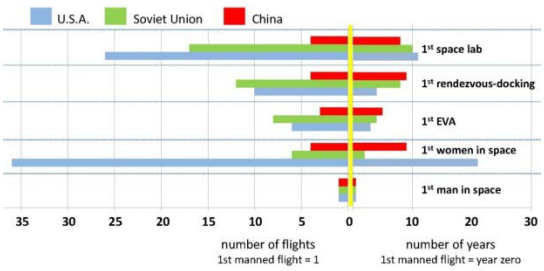

Figure 3: Comparison of space achievements by the U.S.A., Soviet Union and China.

Time is not the main criteria for China. The diagram above shows that compared with the Soviet Union and the U.S.A., China has not been faster in the achievement of its firsts in space. However, China's strength and speciality is its efficiency. The first woman in space, the first EVA, the first rendezvous-and-docking, the first space laboratory has been achieved with fewer flights as compared with the Soviet Union or the U.S.A. For example, China achieved its first EVA during its 3rd manned mission while the Soviet Union accomplished this feat on its 8th flight and the U.S.A. on its 6th flight. (Fig. 3) China might move slowly, but with respect to efficiency-performance it is a global champion.

7. CLEP – China's Lunar Exploration Programme

The Moon is China's test case. Choosing the Earth's natural satellite for a bold exploration programme gives China versatile opportunities to learn and gain experience in development, testing and operations. The Middle Kingdom aims with its lunar robotic exploration programme at laying the foundation for its future deep-space exploration, to develop its space science base and to promote innovation and international cooperation.

7.1 Chinas lunar overtaking lane

In a somewhat natural but also well-thought through move, China decided to design it's lunar exploration programme in phases. For each phase two missions

were planned. This phased approach allowed for a step-wise build-up of capabilities and allowed the opportunity to study, analyse and learn after each phase to be better prepared for the next one.

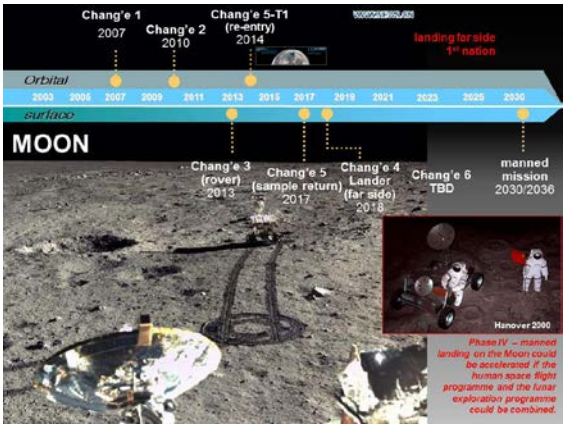

Figure 4: Time line of CLEP.

For the first phase - the launch of a lunar orbiter - the appropriate telemetry, tracking and control (TT&C) systems had to be in place. Furthermore, a launch system and launch vehicle system for a lunar trajectory was needed, as well as ground systems and last but not least, the lunar satellite itself. Interesting to note is that these satellites, named after the ancient Chinese Moon princess Chang'e, have a DFH-3 bus heritage along with China's Beidou navigation satellites and the Tianlian data relay satellite. On 24 October 2007, the Chang'e 1 launch became the operational start of CLEP. The lunar orbiter mapped the Moon and impacted on 1 March 2009. Already Chang'e 2, the back-up of Chang'e 1, showed the world that China is about to speed up for overtaking. Chang'e 2 launched on 1 October 2010 for a high-resolution mapping mission of the Moon. Because of fuel savings the mission could be extended, during which the satellite flew to the Earth-Sun L2 Lagrangian point in 2011, and past asteroid Toutatis in 2012. The mission, initially planned for 6 months is still operational and is still used for deep-space network testing.

CLEP's second phase for lunar landing was initiated with the launch of Chang'e 3 at the end of 2013. Additionally for this phase, deep-space TT&C capabilities were readied, the launch site for the new generation launch vehicle adapted and a lander plus rover designed. Chang'e 3 soft-landed on the Moon's surface and deployed the Yutu rover that roamed for 114 metres before failing on 25 January 2014. After Chang'e 3 it was expected that the back-up satellite Chang'e 4 would head its way in the direction of the Moon before phase 3, the lunar sample return mission would be prepared. But instead of Chang'e 4, Chang'e 5-T1 launched on 23 October 2014 for testing re-entry ahead of CLEP's phase 3. Chang'e 5-T1 was a Chang'e 2-like service module that carried a test sample return space craft, nick-named 'Xiaofei'. 'Xiaofei' was a downscaled Shenzhou capsule flying on a lunar trajectory to the Moon before returning to Earth, for testing high-speed, atmospheric re-entry. Chang'e 5-T1 service module has since travelled to the Earth-Moon L2 point and returned. It is still in lunar orbit and used for testing manoeuvres and mapping landing sites for Chang'e 5, the actual sample return mission.
Chang'e 5-T1 saw another surprise. On board was a commercial payload, the 4M – Manfred Memorial Moon Mission in memory of the late OHB founder, Manfred Fuchs. 4M became the first privately financed Moon mission. It carried a radio beacon and a radiation dosimeter and attracted significant media attention. The radio signals from the beacon where received by radio amateurs worldwide.

In the meantime, a new mission profile was planned for Chang'e 4. It will, around 2018, become the first landing mission on the far side of the Moon. With Chang'e 4, just a back-up of Chang'e 3, China will write space history, turning from a follower into a pacemaker. Before, Chang'e 5 is supposed to launch in 2017, aiming for a sample return mission and entering the – so far – final stage of China's three-step 'orbit, land, return' lunar expedition project. For that mission China will have ready its new generation Long March 5 heavy-lift rocket launcher whose lunar orbital capacity is essential for the mission's success. Chang'e 5 should return 2 kg of lunar soil, including subsurface soil from a depth of 2 m.
According to CLEP's plan, Chang'e 6, the back-up of Chang'e 5, should also be a sample return but since we have seen how efficient and careful China is able to re-purpose missions and flight profiles, Chang'e 6 might take on some very special tasks. For sure it will not end up in a museum.
According to China's 'Roadmap 2050', a manned Moon landing could be anticipated sometime after 2030. Time will tell.

8. Science on the horizon

Since the beginning of China's space efforts, the country has been criticised for not performing space science. Apart from commercial applications, the most emblematic project, the human space flight programme,

was reflected as merely satisfying prestige and to show-off. Slowly but surely, China's space dream is beginning to embrace space science. Despite the failed first attempt to reach the Red Planet with Yinghuo 1, the Mars orbiter which flew piggyback on the Russian Fobos-Grunt sample return spacecraft, Mars remains in focus for the Chinese. Having learned enormously from CLEP, its 2020 Mars mission goes bold: launching in 2020 with arrival at Mars in 2021, the Mars probe will accommodate lander, rover, and orbiter – all in one mission. If China succeeds, the tortoise image might be gone forever.

But already the recent Chinese science missions have earned worldwide respect. On 17 December 2015, the dark matter particle explorer DAMPE satellite was launched. April this year, saw the Shijian 10 retrievable science satellite with international scientific experiments onboard, successfully complete its two-week mission. For most observers, the science highlight of the year is the QUESS project, which included the launch of a quantum satellite and the construction of four ground-based stations to facilitate quantum communication.
Later this year, HXMT, a hard X-ray telescope and a new, second generation of Chinese geostationary meteorological satellites, Fengyun-4A, will be launched. And the next 5 years have equally ambitious missions on the list:
SMILE is a science explorer mission for the observation of solar activities and their impact on the Earth environment and space weather, the analysis of water recycling and for probing black holes. It is a project in cooperation with ESA.
MIT, the Magnetosphere-Ionosphere-Thermosphere coupling exploration probe is for the investigation of the origin, acceleration and transport processes of ions in the polar regions, and to discover the key mechanism for magnetosphere, ionosphere and thermosphere coupling.
WCOM will be a Water Cycle Observation Mission, to understand the Earth's water cycle by simultaneous and fast measurement of key parameters such as soil moisture, ocean salinity and ocean surface evaporation.
ASO-S is supposed to become an Advanced Space-borne Solar Observatory for solar observation to understand the causality among magnetic fields, flares and coronal mass ejections.
Einstein-Probe would aim at the discovery of quiescent black holes over all astrophysical mass ranges and other compact objects via high-energy transients.

9. Political Context

Space and politics are not always best friends but there is no denying that both interfere with each other. We have seen before that political context is important to understand China's space programme, maybe even any space programme in the world.

9.1 BRICS

China is one of the BRICS member states, which also includes Brazil, Russia, India, and South-Africa. BRICS is an association of emerging economic powers to find its place in a multi-polar world. Next to economic considerations, cooperation in the area of technology and science is another strong agenda point. Apart from Russia, none of these countries is part of the ISS project. Last year, before the BRICS summit in the Russian town of Ufa, the possibility of a joint space station was discussed. This year in May, a more concrete idea was on the table when Igor Komarow, the Director of Roscomos State Corporation told reporters: "The practical initiative, on which we are now working together with the BRICS countries, is a data exchange in distanced probing of the Earth, which will help in quicker responses to emergency situations, natural calamities, pollution and other aspects. I believe, it will find rather prompt and very important practical use for the BRICS countries."

9.2 SCO

Another important institution is the SCO - Shanghai Cooperation Organisation, founded in 2001. Member states are China, Russia, Uzbekistan, Kazakhstan, Kyrgyzstan, Tajikistan, and observers are: Mongolia, India, Pakistan, Iran, and Afghanistan. The organisation represents 1/4 of the world‘s population and is the biggest regional organisation. While it aims at interaction and confidence-building measures in Asia, cooperation on political, scientific-technological, cultural, the economic level, and ensuring peace and security for the Asia-Pacific region all member states are important for the China-led ‘One Road-One Belt’ initiative, a massive infrastructure project and economic corridor across the Eurasian landmass including the bordering oceans.

9.3. One Road – One Belt

The project's full name is ‘New Silk Road Economic Belt and Maritime Silk Road’ and was initiated by Chinese President Xi Jinping in 2013. Its idea is the revitalisation of the Eurasian Silk Road model to create a bridge between Asia and Europe. It is complementary to Russian President Vladimir Putin's Eurasian Trade

Zone. Those initiatives will include the areas of energy, aviation, telecommunication, shipbuilding, high-speed trains, transportation, agriculture and cooperation in neighbouring regions. Terrestrial infrastructure will be in need of space infrastructure for management, maintenance and operation. The Chinese Beidou satellite navigation system, together with the Russian GLONASS system will fill this function easily. There are already big discussions about commercial space applications triggered by the 'One Road-One Belt' project and renowned satellite data providers are getting ready for entering this completely new market. Connecting and developing the land areas of Eurasia will change and prepare this region for the future. China is ready to extend the 'Chinese Dream' to the 'Asian-Pacific Dream', stressing that the agenda of the 21st century is the creation of wealth for 99% of the global society in a multi-polar world. Space will be a noble tool to support those efforts.

9.4 China and the United Nations - UNOOSA

It is no secret that China would have been eager to participate in the International Space Station project. Unfortunately, this fell through because of objections by the U.S.A. It is also not a secret that China made several approaches to promote its own future space station to be used by the international community. Being left out of the closed club ISS, China took a highly interesting decision and offered its future space station resources to the United Nations, the most universal multi-lateral organisation. China's first taikonaut, Yang Liwei, as well as China's first female taikonaut spoke on several occasions in front of the audience of the annual COPOUS (Committee on the Peaceful Uses of Outer Space) sessions of the United Nations Office for Outer Space Affairs (UNOOSA) and invited the world community to join China's space station project.

Although UNOOSA is already in existence since the late 1950s, China only joined this UN organisation in 1980. But since then, the China Manned Space Agency (CMSA) has established a long-term cooperative relationship with UNOOSA. The CMSA fully supports promoting international cooperation within the framework of the HSTI, UNOOSA's Human Space Technology Initiative. CMSA aims at more cooperation and exchange with developing countries, sharing experience and resources of China's manned space programme, and to work with other countries to promote the human exploration of outer space.

Year-after-year, China is presenting during the annual COPOUS session in Vienna and the content has remained consistent until today: "Progress of human space exploration results from the collective efforts and the comprehensive wisdom of humanity. For that reason all countries in the world deserve the opportunity to participate in it and share resources with others. Any country in the position to do so should shoulder the obligation and responsibility to promote the technical results of human space exploration to other countries and share space resources with them. During the construction of the Chinese Space Station we will adhere throughout to the principles of equality, mutual benefit and the peaceful utilisation and common development in conducting extensive cooperation with the UNOOSA and other space agencies and organisations all over the world." [9]

Figure 5: China's proposals for UNOOSA's HSTI.

The following 4 main options for participating in the CSS were repeatedly offered by China to UNOOSA's HSTI (Fig. 5):

1. Cooperation in platform technology: either technical cooperation in individual facilities or assemblies or cooperation in the development of sub-systems or modules.

2. Cooperation in space applications: joint research or experiments on-board to cooperate in the fields of space science and applications, space medicine, etc.

3. Astronaut selection and training: exchange and cooperation in astronaut selection and training methods. China is willing to help other countries to select and train astronauts to fly together with Chinese astronauts.

4. Promote and share technical know-how: China will promote and share the technical knowledge and results to/with other countries, especially the developing countries and regions.

In the first quarter of 2016, UNOOSA and CMSA signed a Framework Agreement and a Funding Agreement to develop the space capabilities of UN member states via opportunities on-board China's future space station. CMSA is giving developing countries in particular, the opportunity to conduct space experiments on-board China's space station, as well as to provide flight opportunities for astronauts and payload engineers.

During China's 1st National Space Day, on 24 April 2016, China's first astronaut Yang Liwei reiterated this attitude when he told Chinese media: "The future of space exploration lies in international cooperation. It's true for us, and for the United States too. China will not rule out cooperating with any country, and that includes the United States. Payload has been reserved in the Chinese space station, due to enter service around 2022, for international projects and foreign astronauts. Upon request, China will also train astronauts for other countries, and jointly train astronauts with the European Space Agency." [10]

10. How could the future look like?

There is no doubt that the space exploration of the future will not take place without China. The authors of this paper are part of the Sino-European GoTaikonauts! team which has closely accompanied China's space efforts for the last decade. Having seen its dynamism, inspiration, but also modesty and perseverance, each one of us was looking at China's space dream from a different angle, according to personal interest. We have dared to give an outlook on China's future in space. (Fig. 6) Although we are all convinced that Chinese space activities will increase and grow, we diverge a little bit on the speed and pace of how this will happen.

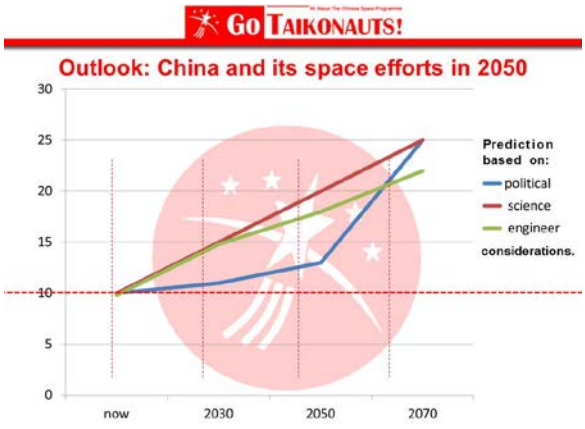

Figure 6: Options for the future development of China's space programme.

The **scientist** (red graph in the diagram) says: Space exploration will remain important in China. The efforts will continue to grow linearly because space science and technology is considered to be a tool for the development of the overall society. Space is a fundamental desire of mankind. It has the image of being a high-tech area. It is extremely difficult and by challenging space, any society can demonstrate its capabilities.

The **societal focussed opinion** (blue graph in the diagram) says: space exploration in China will remain important, but other issues (climate change, energy, social welfare, infrastructure projects – also on a global/Asian/African scale) will require more resources. Once, the creation of a harmonious, possibly global, society is achieved, space exploration will experience a renaissance.

The **engineer** (green graph in the diagram) says: China has a good track-record in completing its space plans, which have been demonstrated in the manned space flight, lunar exploration, Beidou navigation system and other civil and military programmes. So, it is very reasonable to predict that China will continue its fast expansion in space, but with a pace consistent with the slightly slowed-down growth rate of its economy. Although there are many challenges ahead, we will see China becomes the second space power after the U.S.

11. Hare or tortoise?

The characteristics of China's space programme can be described in many illustrative ways. Comparison helps to understand but is often short of the full explanation or insight.

Being a tortoise might mean to be slow. But as the fable tells us, slowness can be compensated with persistence, endurance and dedication. Being a hare can be an advantage in the short-term and it might give you the opportunity for having a rest more often, as long as you do not forget to set the alarm clock…

China's space programme is neither hare nor tortoise. In the beginning of its space efforts until approx. the 1990s yes, China's space programme was slow. It can still be slow, namely in the process before a decision is taken. However, if the environment is holistic, the frame is set and decisions are taken, things speed up enormously and the tortoise converts into a hare. In particular in the execution of programmes, China has proven speed is not magic. Even more so – and this is really specific for China – leaps forward are possible and advance the whole process. One can state with confidence that 'leap-frogging' is a Chinese speciality.

And something else comes to one's mind when looking at the Chinese space programme. There can be comparisons drawn with a menu in a Chinese restaurant. Guests in a Chinese restaurant are often taken by surprise studying the gigantic menu. The trick is that there is a certain set of basic components that may be combined for an almost unlimited number of dishes. The Chinese space programme often works in the same way. So, next time you sit in a Chinese restaurant, please, think of the Chinese space programme… and frogs…

12. Conclusions

- China has its own pace of space.
- China has set sail on a highly visible, moderate-cost space programme aimed at showing world-class capabilities.
- China's political leadership strongly believes that a robust space programme can promote innovation, technology development, and educational benefits.
- China's economic growth will not indefinitely translate via low labour costs. Economic growth of the future will be defined by science, innovation, and technological creativity. Space is one of the best tools for this.
- China is joining the competition in the space industry, in particular in satellite manufacturing and launching.
- China welcomes the challenges of the market for space science applications and to make best use of it.
- China is incorporating into its space programme comprehensive international cooperation and more involvement in international organisations.

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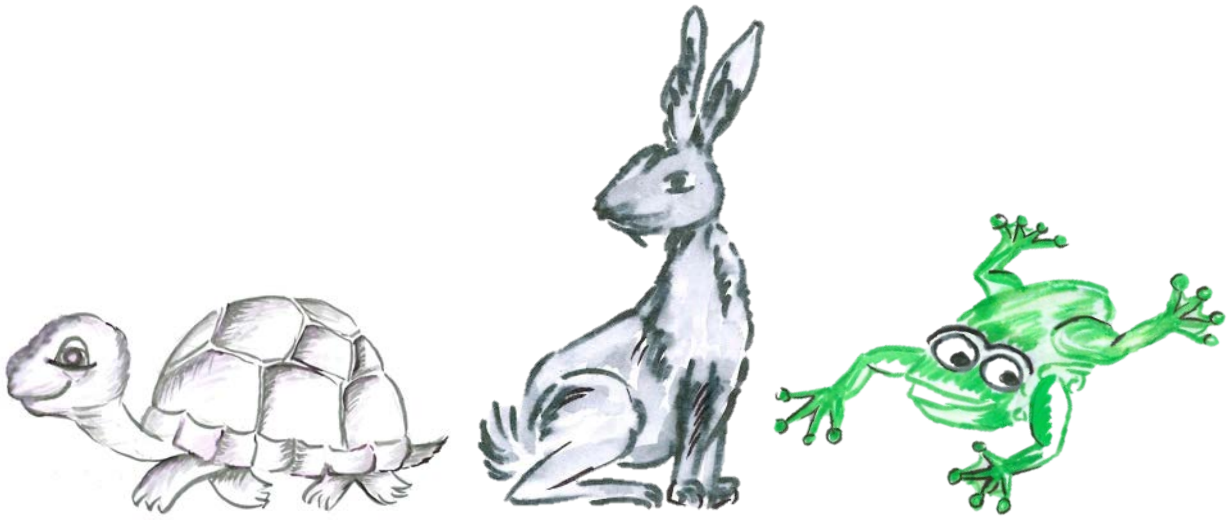

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