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Smaller Satellites for Pakistan – Applications, Cost Analysis & Design Philosophy

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Abstract—**Rapid advancements in semiconductor electronic technologies have been observed during last decades. Extreme compactness, lessened volumes, minute power requirements, reduced masses of COTS components and advanced ruggedization techniques momentously pushed space industries to focus on smaller satellites in order to achieve their aims and objectives. Services delivered by massive ancient satellites are now being obtained by light modern satellites, giving clear advantage in terms of cost, schedule and management. Mission success can be touched with little workforce and reduced risks causing easy access to space as well as encouragement for future missions; which are highly required for Pakistan. This article focuses on significance of smaller satellites (typically less than 200 kg) and the potential services they can provide. It also enlightens a cost effective and swift design philosophy for spacecrafts termed as *Concurrent Lean Systems Engineering*, highlighting critical aspects of satellite development process. It is a novel hybrid of *Lean Systems Engineering* and *Concurrent Engineering*. Moreover, the manuscript includes results of cost analysis on certain interesting smaller satellite missions e.g. PROBA-V, NEOSSat, SSETI Express, SpriteSat, SNAP-1, QuakeSat, UKube-1, PhoneSat 2.5 and Xatcobeo, etc.**

Index Terms—**Concurrent-lean systems engineering, lean thinking, smaller satellites, space mission cost.**

I. INTRODUCTION

SPACE missions are pride of a nation. However, they require vast technological infrastructure, capable launch vehicles, experienced staff, competent project management and a huge amount of investment. Large scale satellites cost excessively as more expenditure is required for complex design, procurement of components, assembly and integration, testing, repairing, storage, transportation and launching. Time frames required for completing such complicated missions by the developing nations are generally too large due to limited funds, lack of expertise, unavailability of space grade components, political issues, restrictions and other constraints. That is why the space competition has been among only few developed regions of the world i.e. *USA, Russia, China,* and *Europe* [1].

Failure of a long term mission results in intense frustration and discouragement for the project team as well as wastage of resources, time and energy of the nation. As a consequence big satellites have proven to be unsuitable for developing countries at the commencement stage of their space programs. Space missions are one-time tasks and generally the satellites once launched cannot be simply repaired or restored in case of failure. Major problem in successful satellite development process is the incapability of simulating pure space environment on the ground. Due to this reason a risk factor is always present that whether the developed system will work fine in space atmosphere to achieve its objectives or not. Generally, failure of smaller satellite missions is relatively bearable than larger ones as they do not harm much in terms of cost, schedule and energy.

Pakistan has developed three smaller satellites so far namely: ***Badr-I*** *(52 kg),* ***Badr-II*** *(68.5 kg)* and ***iCUBE-1*** *(1.1 kg)*. *Badr-I* was launched in 1990, *Badr-II* was launched in 2001 and *iCUBE-1* was launched in 2013 which is also the first *CubeSat* of *Pakistan*. It was entirely developed at university level by *Institute of Space Technology (IST), Islamabad, Pakistan*. Keeping in view the drastic progress in the scope of space technology, the country needs to reduce the time gap between satellites' launches from decades to years and must start several smaller satellite missions in parallel. There is also a need of high collaboration between *Pakistan's* space industry and academia because the trends of space technology are shifting towards academic institutes all over the world. Due to the widespread applications and scope of smaller satellites, many foreign universities are developing smaller satellites at a higher frequency. Such institutions conduct research and novel experiments first and then the technology is transferred to the space industry.

To avoid mission failures, development of satellites is required to be done in a systematic, organized and efficient way. *Systems Engineering (SE)* is a field that enlightens a top-down system development process based on certain critical phases in the project life-cycle [2]. It is applied in many industries for developing optimized products. For engineering a spacecraft, top level requirements of the space mission are initially outlined according to which, product specifications are determined. Mission requirements are extended to system level, subsystems' level and units' level requirements. On the basis of these defined requirements and specifications development of system is initiated. *SE* provides tools that are used for undertaking complex projects effectively on the basis of cost, schedule, scope and quality [3]. There are numerous ways for developing a satellite system, however *SE* facilitates effective decision making and picking the best out of possible options to produce a refined and ideal product.

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TABLE I. TYPICAL CLASSIFICATION OF SPACECRAFTS W.R.T CRITICAL PARAMETERS

Class	Mass (kg)	Max. Bus Power (W)	Cost (US$ M)	Development Time (yrs)	Orbit	Mission Life (yrs)
Large satellites	>1000	>1000	100–500	5–10	GEO, MEO, LEO, HEO	10–20
Small satellites	500–1000	1000	30–300	2–5		5–10
Mini-satellites	100–500					
Micro-satellites	10–100	150	10–150	1–3	LEO, HEO	2–6
Nano-satellites	1–10	20	0.1–10			1–3
Pico-satellites	0.1–1	5	0.05–2			
Femto-satellites	<0.1	1	<0.05	<1		<1

The article presents importance of smaller satellites (typically less than *200 kg*) for *Pakistan*. There are many advantages on focusing smaller satellites instead of developing large ones. Widespread applications and potential services of small satellites that provide a bigger-picture approach to the problem solvers for solving various problems have been discussed. The paper includes results of our cost analysis on several satellite missions. A novel design philosophy for the design and development of satellites is described, which is the blend of *Lean Systems Engineering* and *Concurrent Engineering* viewpoints. Large satellites can have mass more than ***8000 kg*** while miniature satellites can be as small as ***50 g***. Due to a wide range of mass and bus power, satellites are categorized in various classes. As described in [4], [5], and [6], the widely accepted classification of spacecrafts has been outlined for clear understanding of the readers in Table I.

II. WHY SMALLER SATELLITES?

Advancements in *very-large-scale-integration (VLSI)* technology, led to the production of compact sized sensors, actuators, processors and other electronic components [4]. Innovative electronic technologies facilitated the development of smaller satellites with similar or even better capabilities than their large counterparts. Although such spacecrafts cannot completely replace the entire capabilities of large systems yet they are a remarkable complement to them. Smaller satellites can provide solutions for up to ***80%*** of mission needs at only around ***20%*** of cost when compared with big satellite missions [7]. Small missions have been proved as source of motivation for the scientists and engineers, who waited for decades to analyze the space related data. Entire team gets stimulated, refreshed, and sharpened when given a chance to conduct such high-priority and relatively simpler projects that can be completed within thin time frames.

Generally instead of ***3–5 years***, such satellites can be manufactured and made ready for the launch just in ***9–36 months***. *SNAP-1* and *SSETI Express* are the dominant examples of such missions. *SNAP-1* was developed by *Surrey Satellite Technology Ltd (SSTL), UK* in a time span of not more than ***9 months*** [6]. The total cost of *SNAP-1* mission was just around ***US$ 1.55 million*** [6]. Likewise, *SSETI Express* was manufactured by the *European Space Agency (ESA)* at a cost of about ***US$ 120,000*** only [9]. The spacecraft was developed and launched in a time period of just ***18 months*** [9]. The acceptable risk ratios and encouraging prospects of smaller spacecrafts have brought forth a chance for Pakistan to build indigenous satellites and access the space swiftly to fulfill its problem solving needs. In the light of [7], smaller satellite missions have following advantages:

TABLE II. TYPICAL POWER BUDGET OF SMALLER SATELLITES [8]

Satellite Subsystems	Percentage of Max. Bus Power (< 300 W)
Payload	20–50 %
Power	10–30 %
Communications	< 15 %
Command & Data Handling	~ 5 %
Attitude & Orbit Control	< 15 %
Thermal	< 5 %
Propulsion	~ 0 %

- Less development cost and reduced launch cost.
- Requirement of smaller ground station networks associated with fast and cost effective data distribution methods.
- Short development times allow rapid access to space.
- Credibility assessment of design as well as indigenous components can be performed in space. Tested designs can be scaled to larger spacecrafts in the future.
- Frequent opportunities of novel experiments and faster return of scientific or application data allows speedy growth of technical and scientific knowledge database.
- Timely success creates inspiration and encouragement among the project team for future missions.
- Smaller satellites enable greater collaboration of local universities with space industry.
- Smaller satellite projects require little workforce thus multiple missions can be carried out concurrently in small teams within an organization.
- Smaller consortia lead to less conflicts and better team coordination during mission life-cycle.
- Designs of smaller satellites are relatively less complicated. Hence, management and quality assurance procedures can be performed effectively.
- Commercial availability of highly reliable spacecraft buses e.g. *Arkyd-3 (15 kg), SSTL-70 (70 kg), SSTL-100 (100 kg), ATK-100 (77 kg)* etc. that can be procured and utilized instead of developing newer platforms.
- Instead of a single giant satellite with numerous objectives, multiple smaller satellites can be built having separate objectives to divide the risk of complete mission failure.
- Multiple smaller satellites can be launched by a single launch-vehicle. They can fit as secondary payloads on large satellite launchers; thus avoiding the wastage of vacant space in the launch-vehicles.
- Mission failure is comparatively bearable in terms of cost, time and energy.

III. POTENTIAL SERVICES AND APPLICATIONS

Smaller satellites have huge scope and they are now delivering similar or even improved services which were formerly obtained by large satellites. ***RapidEye*** (constellation of *five* earth observation satellites) was injected to space in 2008. Each *RapidEye* spacecraft has a mass of nearly 156 kg and it provides images with *5 meters* spatial resolution. However, ***SkySat-1*** spacecraft (launched in 2013) has a mass of just around *83 kg* and it is delivering high quality images with an enhanced spatial resolution of *2 meters*. *SkySat-1* is about ***20 times*** smaller than traditional spacecrafts. Some potential services and specific applications of smaller satellites for *Pakistan* are stated below.

A. Space Sciences

Observation, measurement and analysis of space atmospheric parameters e.g. solar extreme ultraviolet radiations [10]; atmospheric luminous emissions [11]; electromagnetic radiation in specific orbits [12]; flux and energy of energetic particles in radiation belts and upper atmosphere, wind speed, ion drift velocity and *DC* component of electric field [13]; effects of solar variations and small scale fluctuations in ionosphere that can lead to radio scintillation [10] [13]; ozone layer depletion [14]; atmospheric aerosols and seasonal variations at various altitudes [15] etc.

B. Earth Sciences

Monitoring temporal variations in Earth’s gravitational field [16]; spectrometry of a wide range of atmospheric species and greenhouse gases, active and passive microwave imaging [7]; scientific observation of terrestrial gamma-ray flushes [11]; crop growth monitoring and yield prediction, identifying river current water damage, assessment of destruction caused by earth quakes, weather monitoring, observation of fog and fumes; forecasting the probability of earthquakes; detection of forest burning, fire points and active volcanoes; fish potential zone identification, sea mapping, monitoring of sea water level and glaciers; delineation of flood potential and drought zone etc.

C. Communication

A network of small communication satellites in *low-earth-orbit (LEO)* can provide coverage over the entire globe. *Iridium NEXT* constellation is the fresh example of such missions. There are 66 satellites (each having *50 kg* mass) in this telecommunications network which will provide 24/7 complete earth observation to the host government and scientific organizations as well as communication links between other satellites and ground stations throughout the world [17].

D. Technology Demonstration and Experimentation

Demonstration of new technology, credibility assessment of design and conducting novel experiments are some more appealing applications of smaller satellites. *Delfi-C3, TUBSAT-A,* and *GeneSat-1* are the finest examples which lie under this category. *Delfi-C3* was a nano-satellite in which performance analysis of novel *Thin Film Solar Cell (TFSC)* technique and an *Autonomous Wireless Sun Sensor (AWSS)* with its intra-satellite *RF link* for data transfer to onboard computer was conducted. *TUBSAT-A* was launched to space for technology demonstration and credibility assessment of the spacecraft’s design for future missions. Many technologies being used for *SEPSAT* spacecraft are based on the proven heritage from small satellites *BeeSat* and *TUBSAT*, which were developed by *Technical University of Berlin, Germany* [10]. *GeneSat-1* was launched to perform biological experiments pertaining to effects of microgravity on bacteria. Table. III shows a collection of smaller satellite missions with their main objectives in light of [18], [19] and other specified citations.

E. Military

Military applications include border surveillance, spying, reconnaissance, observation of enemy’s movement, assessment of damage during combats, early warning of incoming missiles or aircrafts, widespread communication for effective coordination among local troops etc.

IV. COST ANALYSIS

The overall cost of space missions does not depend only on the manufacturing of satellites. Rather each parameter in equation (1) generally constitutes the entire cost of a space mission [4]. Typical values of these parameters are also provided underneath. The average cost of launching each kilogram mass to *LEO* is about ***US$ 12,000*** and to *GEO* is about ***US$ 30,000*** [1]. The minimum monthly cost of bandwidth is about ***US$ 3,500*** per MHz [20]. Maintenance or operations cost for a satellite should also be considered as after launching one into orbit, the spacecraft has to be monitored from a ground station, which requires regular maintenance as well as skilled manpower. Moreover, in case of mishap the multi-million endeavors can either end up in fragments or sustain damages that will cost more to repair [20].

A *1U CubeSat* mission (including launch) typically costs *US$ 150,000* to *US$ 1.5 million*, rather than *US$ 200 million* to *US$ 1 billion* for a big sized one [21]. The entire mission cost of *iCUBE-1* was about ***US$ 100,000***. The development of the satellite and infrastructure expensed approximately ***US$ 35,000*** [22]. *Interorbital Systems Corporation (IOS)*, an aerospace company in *California, USA*, provides a *TubeSat Personal Satellite Kit*, just for ***US$ 8,000***. This cost also includes the launch price of the pico-satellite to *LEO* [23]. A *TubeSat Kit* weighs *0.5 kg* in which additionally up to *0.25 kg* payload can be installed. Similarly, *PocketQubes* are the miniaturized satellites that weigh just around *200 g* and can be used for minor experiments in space. For a *1P PocketQube* the total mission cost (development plus launch) is nearly ***US$ 35,000*** [24].

NASA has been working to reduce the cost of developing and launching innovative smaller spacecrafts and also has focused on non-space ***commercial-off-the-shelf (COTS)*** technologies to significantly lower the expense. *PhoneSat-1.0*

$$\underset{(100\ \%)}{\text{Overall Mission Cost}} = \underset{(60\text{ to }70\ \%)}{\text{Satellite Cost}} + \underset{(20\ \%)}{\text{Launch Cost}} + \underset{(10\text{ to }20\ \%)}{\text{Cost of Lifetime Operations}} \tag{1}$$

TABLE III. SMALLER SATELLITE MISSIONS WITH THEIR MAIN MISSION OBJECTIVES

Satellite	Mass	Launch	Manufacturer	Main Mission Objectives
FalconSAT-5	180 kg	2010	USAFA, USA	Space weather detection, VHF signals distortion measurement [25]
RapidEye	156 kg	2008	MDA, Canada	High quality commercial earth observation (Resolution 6.5 m) [26]
PROBA-V	138 kg	2013	Qinetiq Space NV, Belgium	Multispectral imaging to study evolution of vegetation [27]
SloshSat-FLEVO	129 kg	2005	ESA, Europe + NLR, Netherlands	To investigate the behaviour of liquids (sloshing) in space [28]
Picard	120 kg	2010	CNES, France	To monitor solar dynamics and study their effects on earth's climate
KITSAT-3	110 kg	1999	KAIST/SaTReC, South Korea	Testing of new satellite bus and payloads, Study space sciences
NigeriaSat-1	100 kg	2003	SSTL, UK	Earth observation and disaster monitoring (Resolution 32 m)
BIRD	94 kg	2001	DLR, Germany	Bi-spectral earth observation to detect fires/hot spots [29]
SkySat-1	83 kg	2013	Skybox Imaging Inc., USA	High quality commercial earth observation (Resolution 2 m)
NEOSSat	74 kg	2013	CSA + DND/DRDC, Canada	Search and track near earth objects (asteroids, satellites etc.)
Badr-II	68.5 kg	2001	SUPARCO, Pakistan	Assessment of Indigenous design credibility, Earth observation
SSETI Express	62 kg	2005	ESA, Europe	Deploying 3 CubeSats, Design evaluation, Earth observation [30]
Badr-I	52 kg	1990	SUPARCO, Pakistan	Satellite communication testing, Evaluation of indigenous design
MAROC-TUBSAT	47 kg	2001	TU Berlin, Germany	Earth observation and vegetation detection (Resolution 300 m)
SpriteSat	45.3 kg	2009	Tohoku University, Japan	To monitor luminous emissions "sprites" in upper atmosphere [31]
TUBSAT-A	35 kg	1991	TU Berlin, Germany	Technology demonstration, Design trustworthiness assessment
Astrid-2	30 kg	1998	SSC, Sweden	Measurement of E-field, B-field and UV absorption in aurora
TechnoSat	20 kg	2016	TU Berlin, Germany	On-orbit evaluation of nano-satellite technologies and components
AprizeSat-3	13 kg	2009	Aprize Satellite Inc., USA	To assess a novel automatic system for detecting ships on oceans
Itamsat	11 kg	1993	AMSAT, Italy	To demonstrate and assess radio communication technology
SNAP-1	6.5 kg	2000	SSTL, UK	Assessment of COTS components for observing satellites in space
Spore Sat	5.5 kg	2014	NASA/ARC, USA	To conduct scientific experiments on plant cell gravity sensing
QuakeSat	4.5 kg	2003	Stanford University/SSDL, USA	To predict earthquake activity by ELF magnetic signal data [32]
TurkSat-3USat	4 kg	2013	ITU, Turkey	To demonstrate VHF/UHF communication technology [33]
CanX-2	3.5 kg	2008	UTIAS, Canada	Design credibility assessment, Fast and cost effective access to space
FIREBIRD-I	2 kg	2013	MSU/UNH/LANL, USA	To assess ambiguities of microbursts in Van Allen radiation belts [34]
iCUBE-1	1.1 kg	2013	IST, Pakistan	Imaging of earth and assessment of communication technology [35] [36]
PhoneSAT 2.5	1 kg	2014	NASA/ARC, USA	To assess consumer grade smartphone technology in a CubeSat [37] [38]

and *PhoneSat-2.0* are the result of such struggles having development costs of just around *US$ 3,500* and *US$ 7,000* respectively [38]. Cost of a satellite mission not only depends on the spacecraft's mass but also on specifications and quality of the payload; which is a key driver of the design. The trend of mission cost with respect to spacecraft mass has been presented in Fig. 1 and Table. IV [18] [19].

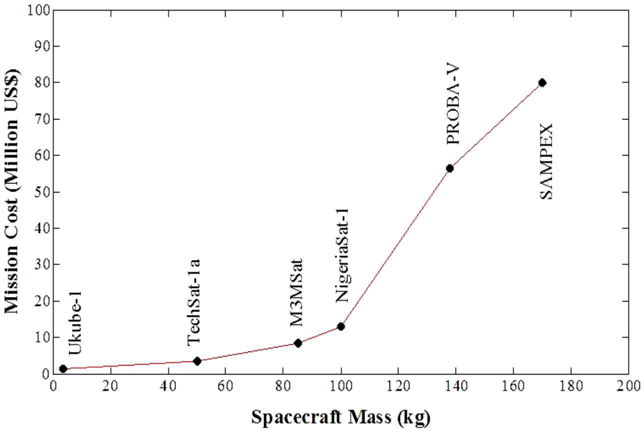

Fig. 1. Mission cost of space programs w.r.t spacecraft mass

V. DESIGN PHILOSOPHY

A low cost and swift space mission can be achieved by following an effective design philosophy. It is not necessary that all the smaller satellite missions will be of low cost and shorter time periods. Application of a systematic design

TABLE IV. ESTIMATED MASS AND COST OF SOME SATELLITE MISSIONS

Satellite	Mass (kg)	Launch	Mission Cost (US$)
EnviSat-1	8211	2002	2.9 billion [39]
ERS-1	2384	1991	933 million [40]
ORS-1	475	2011	226 million [41]
SAMPEX	170	1992	80 million [42]
PROBA-V	138	2013	56.5 million [43]
VNREDSat-1a	115	2013	62.3 million [44]
NigeriaSat-1	100	2003	13 million [20]
ALSAT-1	88	2002	10 million [20]
NEOSSat	74	2013	24 million [45]
TechSat-1a	50	1995	3.5 million [43]
SpriteSat	45.3	2009	3.8 million [46]
SNAP-1	6.5	2000	1.55 million [6]
QuakeSat	4.5	2003	1.8 million [47]
UKube-1	3.5	2014	1.25 million [48]
SkyCube	1.3	2014	0.116 million [49]
Xatcobeo	1	2012	1.35 million [50]

philosophy distinguishes such missions from conventional large ones in terms of cost, schedule and quality. Our prime perspective for reducing cost and time frame of projects and enhancing their quality is well-timed development of a healthy ***project plan*** and a vigorous ***verification strategy***. Time spent on planning before initiating manufacturing processes saves a lot of cost and time during the development phase. The second perspective is ***implementation*** of the developed plans and strategies. It is the most significant part of effective design philosophy because all the plans are moot if they are not being executed and implemented strictly. The third perspective is ***high coordination and communication*** between entire project team. Lack of coordination and bad communication among team members or technical departments causes uncertainties, misunderstandings, mistakes, and faults that ultimately affect the project in terms of cost, schedule and quality; often leading to whole mission failure.

The viewpoint of *Lean Systems Engineering (LSE)* when combined with *Concurrent Engineering (CE)* covers all our three (above mentioned) perspectives of healthy design and development methodology for rapid development of low cost satellites. We have termed this hybrid approach as ***Concurrent Lean Systems Engineering (CLSE)***. *LSE* individually provides an efficient design methodology for product development by reducing waste and enhancing value during the project's life-cycle. *LSE* is the blend of *Lean Thinking (Lean)* and *Systems Engineering (SE). Lean* is a dynamic process through which all individuals in an organization work actively to eliminate waste and to create value. Waste is cut out by *reducing over processing, unnecessary transportation, avoiding delays, timely identification and fixing of defects,* etc. Lean principles were developed by *Womack* and *Jones* [51] based on the original work done by *Ohno* [52] of the ***Toyota Motor Corp***. *SE* is a top-down development approach that focuses on the ***"needs"*** of end user to produce systems with required specifications and to avoid overdesign. The *LSE* promotes increased and healthier *SE* activities with higher responsibility, authority, and accountability leading to better and waste free workflow with higher product assurance.

CE on the other hand, is a philosophy in which design, development, procurement and manufacturing of a product is carried out by real time teamwork whose aim is to significantly lessen the time and cost of development as well as to increase the quality of product as required by the customer [53]. It is also known as *Simultaneous Engineering*. *CE* ensures high integration of tools and coordination between the whole project team. It ensures timely availability of critical design information to all the participants, which is crucial for making healthy decisions. All technical departments involved in mission life-cycle share a same design facility to work in a concurrent way. For most of the complicated projects, all critical design information is not completely available during the initial phases so *CE* maximizes the timely availability of critical information [54]. The cost of performing *CE* activities is low and it has significant positive prospects too. *CE* drastically reduces communication gaps as well as creates harmony among all the teams.

CLSE approach is better than *LSE* and *CE* as it governs the characteristics of both*;* thus promoting healthier decision making ability, improved problem solving environment, compact life-cycles, reduced waste and high quality product development. Fig. 2 shows our design philosophy based on the viewpoint of *CLSE*. Application of *CLSE* approach for developing Pakistani satellites will not let the satellites to deviate from their finalized requirements during the development phase as it provides a clear vision of end product to the project team; thus increasing prospects of a refined and optimized satellite. Design tools of *SE* keep on verifying and validating the product during different phases in project life-cycle which not only minimize errors and mistakes but also assist in their timely identification. As more the delay in identification of an error or fault occurs, the more cost and time is required to recover it. The far sightedness produced by the concurrent design approach in the *CLSE* philosophy, allows minimizing the uncertainties and misunderstandings in the product development and thus reduces the probability of errors and faults.

Another way to reduce time and cost of space projects is the employment of *COTS* modules which undoubtedly saves lot of time that was to be spent on their indigenous manufacturing. However, it is generally needless to build expensive industrial setups for manufacturing such components (i.e. *reaction wheels, magnetorquer rods, star sensors, sun sensors, battery* etc.) when they can be commercially procured within less time. *COTS* hardware of non-space grade can be installed in satellites after their proper ***ruggedization*** together with a design that can protect them from harsh effects of space environment; leading to drastic reduction in the development cost i.e. up to *one-tenth* of complete space grade satellite. On the basis of heritage, reliable *COTS* components are available in many varieties which enabled industries to develop successful satellite systems simply by selecting them according to the end product's specifications. *CLSE* methodology can also be applied on *COTS* based products for smooth completion of the projects.

VI. DISCUSSION

Under the perspective of *SE* there are generally three main types of spacecraft design methodologies: ***Sequential Design***, ***Centralized Design*** and ***Concurrent Design*** [53]. Sequential design approach is the most traditional approach used. The entire design process is carried out in a sequence of activities which are based on successive time intervals. The approach produces uncertainties and misunderstandings among team members and technical departments due to lack of communication and coordination, resulting in the need of extra design iterations. It is a lengthy design approach which introduces delays and time gaps that result as a wastage of human resource. Centralized design approach on the other hand is based on a team of *Systems Engineers*, whom is provided with the subsystems' design information by the specialists of various domains. This team acts as a center of communication and coordination for the entire project. Centralized design approach is better than sequential design approach but its drawback is the communication gap within the

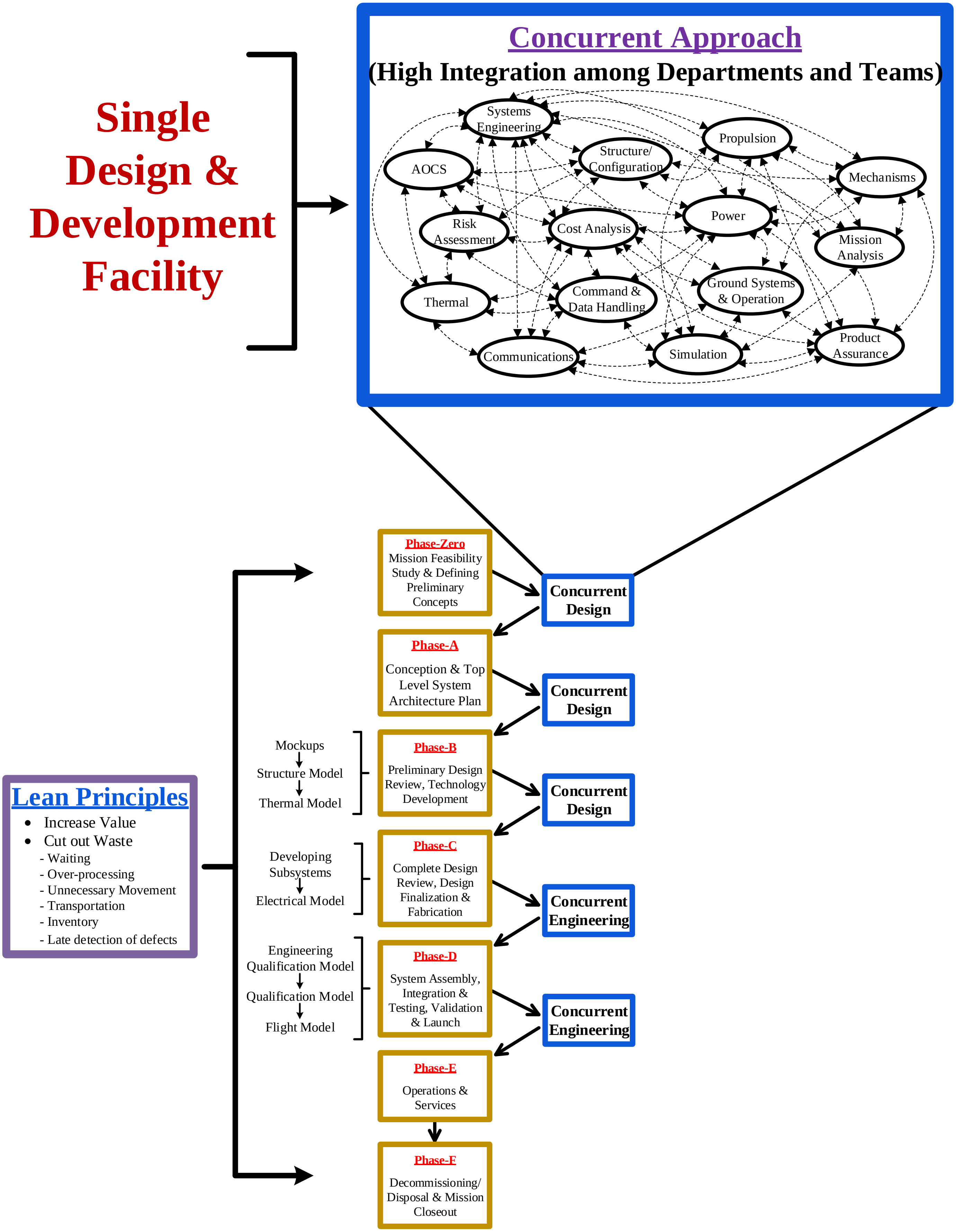

Fig. 2. *Concurrent Lean Systems Engineering (CLSE)* philosophy over the life-cycle of space missions

subsystems' specialists, thus impeding the healthy decision making atmosphere. Concurrent design approach however is the best approach having minimum communication gap among the team members and promoting healthier decision making atmosphere and farsightedness for the project.

European Space Agency (ESA) has developed a ***Concurrent Design Facility (CDF)*** to evaluate the feasibility of novel space missions, purely based on *CD* approach which is now an essential tool used for decision making and for risk management processes [53]. A *Systems Engineer* leads the entire team to dynamically conduct the design process and efficiently manage the project team. *CDF* has reduced the feasibility analysis and study duration in the space missions of *ESA* from ***6–9 months*** to ***3–6 weeks***, which is a major achievement in rapidly developing the spacecrafts [53]. *Lean Principles* are actively being executed in the *United Kingdom Aerospace Industry* [55]. In *United States*, the *Aerospace Sector* of ***Lockheed Martin*** is thoroughly applying the *Lean Principles* to ***F-16***, ***F-22*** and ***C-130J*** aircrafts' production programs [56]. A microsatellite ***USUSat-II*** was designed and engineered under the emphasis of *Concurrent Design* and *Lean Manufacturing* approach, respectively [57].

Pakistan must strictly adopt such healthy design methodology, at academia as well as industry level, to successfully engineer and achieve high quality space missions within small time frames and reduced costs. Cost reduction does not mean to compromise on the quality of product, however its main aim is to cut out waste that can eat a significant quota of the cost budget. The *CLSE* design methodology reduces instability in satellite development processes and gets practically refined as the space industry evolves and becomes mature. In the light of [4], some best practices for undertaking a successful smaller satellite mission are:

- Well-defined mission objectives and constraints
- Highly effective and thorough planning
- Vigorous design and development methodology
- Exceptionally skilled technical staff
- Technically experienced project management
- Small and dedicated teams
- Individual responsibility for work rigor and quality
- Shorter timescale (to prevent change in objectives)
- Physical proximity and good communication between team members
- Strong preventative and precautionary measurements for non-conformance and mismatching (that commonly occurs between modules/units/subsystems) well before the integration process
- Step by step development of each module (unit/subsystem/system) with proper verification as well as monitoring at every step

VII. CONCLUSION

The article concludes profound significance of smaller satellites (less than 200 kg) for nations emerging in space technology, especially *Pakistan*. Smaller satellite missions have plenty of advantages over the large counterparts. They are not only less complicated but also require lesser expenses, resources, work force and development time. Smaller satellites are easy to manage and are appearing to be the right solution for providing numerous applications and services in the modern age. As frequent experimentation is a way to success, smaller satellites not only offer strong opportunities to test reliabilities of novel indigenous designs but also allow executing a series of low cost experiments to nations that are lagging behind in space technology.

Moreover, the article also presents important results of our cost analysis on several smaller satellite missions to give readers an idea about the expenditures of space missions. A hybrid design philosophy known as *Concurrent Lean Systems Engineering (CLSE)* has also been described to smoothly develop high quality spacecrafts with reduced costs and within narrow time frames. *Pakistan* can thus expedite its space program by primarily focusing on smaller satellites with *CLSE* approach and then extending the heritage towards larger satellites in a systematic and organized way.

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