Journal of
Aeronautics & Aerospace Engineering

OPEN ACCESS Freely available online

Research Article

Mathematical Analysis of the Advanced Computing systems and concepts in Lattice Quantum Chromo Dynamics, Computational Cosmology, and Control Engineering in Aeronautics and Aerospace Industry

Kamal Nain Chopra*

Department of Applied Physics, Maharaja Agrasen Institute of Technology, Rohini, GGSIP University, New Delhi, India

ABSTRACT

Designing concepts for Lattice Quantum Chromo Dynamics (QCD), Computational Cosmology, and Control Engineering in Aeronautics and Aerospace have been discussed in this paper. The analytical treatment has been based on expressing the strong interaction between quarks mediated by gluons, and considering the space-time lattice to be distributed across all of the nodes. In addition, the Lattice QCD, as reported in the literature, has been technically discussed. Comparison between Quantum Electrodynamics (QED) and QCD; and the Simulation of large scale structures, cosmic web of dark matter filaments and structure have been described.

Keywords: Advanced computing; Lattice quantum chromo dynamics; Quantum electrodynamics; Computational cosmology; Control Engineering in Aeronautics and Aerospace Industry

INTRODUCTION

Advanced computer techniques and systems

Operating advanced computer systems are based on working with computer architecture, hardware and software and computer systems, which are able to hold a large amount of data and store vast quantities of information. It has to be noted that a computer requires the capability to provide networking resources and advanced software.

The Hartree Centre has provided the high performance computing (HPC) capability needed to enable Dr Neil Ashton of the University of Manchester to develop more complex, more accurate computational fluid dynamics (CFD) models for aircraft designers. Advanced computing and visualisation capabilities at the Hartree means that the Manchester team not only has cut development/run times from months to days, but also has taken the first step towards simulation of a whole aircraft, superseding the previous 'piece by piece' approach. It is expected that these new models will be a major boost to CFD - a key time and cost-saving design tool used by the aviation industry to develop aircraft that use less fuel, generate less noise and produce fewer emissions.

Computational concepts and techniques play a major role in control engineering in Aeronautics and Aerospace, after the advent of putting first computer-based control systems into operation two decades ago. This role has been increasing in the preceeding years as the sophistication of the computing methods and tools available, as well as the complexity of the control problems they have been used to solve, have increased a lot ; especially with the introduction of the microprocessor and its use as a low-cost computing element in a distributed computer control system, largely affecting the way in which the design and implementation of a control system is carried out, and also on the theory underlining the basic design strategies. As a result of the development of interactive computing, a great increase in the use of computer aided design methods and robust and efficient numerical algorithms have been produced for supporting these techniques. Great progress has also been achieved in the languages used for control system implementation, especially the recent introduction of Ada'", a language whose design is based on some very fundamental computer science concepts derived and developed in the recent years. As a consequence of the high rate of change in the field of computer science, the recent developments have been faster than their incorporation into new control system design and implementation techniques.

METHODS

Advanced computer science in aerospace industry

Method of applying Advanced computing to Aerospace Industry is a tough and complicated job; which requires not only the skill

Correspondence to: Kamal Nain Chopra, Department of Applied Physics, Maharaja Agrasen Institute of Technology, Rohini, GGSIP University, New Delhi - 110086, India, E-mail: kchopra2003@gmail.com

Received: January 21, 2021, **Accepted:** March 09, 2021, **Published:** March 15, 2021

Citation: Chopra KN (2021) Mathematical Analysis of the Advanced Computing systems and concepts in Lattice Quantum Chromo Dynamics, Computational Cosmology, and Control Engineering in Aeronautics and Aerospace Industry. J Aero Res. 10:243.

of the designing Aeronautical engineer, but in addition hands on experience of working in the field alongwith great knowledge of the Mathematical equations of Advanced computing. Some engineers with Advanced computing has become indispensable to industries, scientific researchers, and government agencies for the ability to generate new discoveries and to innovate breakthrough products and services. It is now understood that high-performance computers are contributing a lot to scientific progress, industrial competitiveness, national security in Air, and quality of life. This is why, many leading nations are not only engaged in an intensifying contest to develop the most sophisticated high-performance computing systems, but also to broadly deploy them throughout their academic, industry, and government institutions, in order to improve their industrial competitiveness and scientific leadership, national security, and help address social challenges including health, public safety, weather forecasting, climate change, and environmental protection, since they have recognized that more sophisticated and faster computers can give them a comparative advantage and leading edge.

Modern advanced research concentrates beyond the capability and capacity of a single computer for detailed multi-level simulations, data analysis, and exascale computations. In fact, present research examines how to use high-performance computing (HPC) in aviation, e.g. the possibilities of using a national HPC system SIVVP (Slovak infrastructure of the high-performance computing) on the Faculty of Aeronautics, which supports the use of several computing technologies including Matlab, Ansys, Abaqus, Fluent, and compiler Intel Fortran.

The important point about computer science is that it provides an optimum knowledge of both hardware and software. Advances in computer software make it possible to design new systems for pilots, where computer scientists are required for using their understanding of systems design, and their ability to bring hardware and software together, for choosing cockpit components that should run more efficiently. They have to work with the latest software in aviation and aerospace, and offer a safer and more intuitive experience to present day pilots. In aerospace also, computer scientists can help in choosing or custom-designing the hardware needed to launch people and satellites into space, while monitoring their coordinates extensively during launch and after begining of orbit. Custom hardware is an important area in which the computer scientists are in increasingly high demand within the aerospace industry. In addition, Airlines and the other objects bound for space, must include software to plan their launch, target their destination, and monitor what happens to the object in air. The modern aerospace industry is based on using Internet connectivity, continuous monitoring by satellite, and continuous ground communication, and the whole process works through advanced software applications, that were custom-designed for the type of craft being used. Advanced computing was initially used in Aircraft Industry to reduce expenditure. With the advent of Advanced Computing, the aerodynamics of the Aircrat could be studied by performing the aero fluid dynamics (AFD) experiments, not requiring the very expensive wind tunnel Also Boeing Industry was very much benefitted by the Advanced computing systems. In addition, the future Aviation Industry is very much dependent on Advanced Computers for designing various functions for maximizing safety and efficiency. Aerodynamics is a branch of physics that deals with the motion of air and other gaseous fluids, and with the forces acting on bodies passing through such a fluid. Aerodynamics explains the principles governing the flight of aircraft, rockets, and missiles.

There is important difference between Astrophysics and Cosmology. Whereas Astrophysics is the branch of astronomy which deals with the physics of the universe, including the physical properties of celestial objects, as well as their interactions and behaviour, Cosmology is the branch that deals with the nature of the Universe as a whole.

Advanced Computer Techniques Technology was founded in USA about four and a half decades back, and is based on fixing a language compiler on the UNIVAC LARC computer, Initially, it used FORTRAN language, followed by a COBOL compiler, a FORTRAN 77 compiler, and latera Pascal compiler. It evolved gradually, with the reporting of many papers [1-7]. Nain Chopra [8] has discussed a Technical Note on Advanced Computing Concepts with Applications in Particle Physics, Networking, and Data Handling. In the present paper, an effort has been made to extend such a study to the interesting topics of Lattice QCD, and Computational Cosmology.

Mathematical formulae and equations used in advanced computing

Advanced Computing has helped in the rapid evolution and growth of Lattice Quantum Chromo Dynamics, Computational Cosmology, and Control Engineering in Aeronautics and Aerospace Industry, which are briefly discussed below:

As we know, in nature, we come across four types of force: (i) Gravity which explains the celestial motion, and is explained by the general theory of relativity; (ii) The Electromagnetic force, due to the interaction between the nucleus and electrons;(iii) The Weak force, which explains the beta decay of a nucleus; and (iv) The Strong force, that acts between the quarks and gluons, which form protons and neutrons. It is important to note that the leading Research organization-RIKEN BNL Research Center (RBRC) has focused on many types of complex phenomena caused by the Strong Force, including the matter-creating process after the Big Bang. Interestingly, this Strong Force is explained by a theory called Quantum Chromodynamics (QCD). The RBRC has been pursuing it's research projects for explaining various physical phenomena brought by the Strong Force, on the basis of the principles of QCD. RBRC is engaged in exploring as to how the matter was formed after Big Bang i.e., understanding the origin of matter and universe, implying to establish a new field of Physics by coordinating theoretical and experimental research.

It has now been well established that (i) the nucleons and the parity symmetry breaking, are two of the foundations of contemporary particle and nuclear physics; and (ii) the other important property of Strong Force is the Spontaneous symmetry breaking, which plays an important part in the research being carried out for understanding the ultimate law of physics comprising gravity. In fact, these Symmetry breakings in QCD have been the main focus of the research efforts being made by the RBRC. It is worth mentioning here that the electromagnetic force and the weak force are explained in the unified weak theory.

It is to be noted that in theoretical physics, the quantum theory explains the strong interaction between quarks and gluons, the fundamental particles that make up composite hadrons such as the proton, neutron and pion. In a similar manner, QCD is a type of quantum field theory called a non-abelian gauge theory, having symmetry group SU [3]. Interestingly, (i) the QCD analog of electric charge is a property called color, and (ii) Gluons are the force carriers of the theory, just like the photons, which are for the electromagnetic force in quantum electrodynamics. The importance of the underlying physics can be judged from the fact that this theory is an important part of the Standard Model of particle physics. On the basis of many theoretical and experimental investigations, a lot of experimental evidence has been obtained for the QCD. It is important to note that QCD is an important concept as it exhibits two important properties given below:

(ι) Color confinement which is due to the constant force between two color charges as they are separated. This is explained as: With an increase in the separation between two quarks within a hadron, increasing amounts of energy are required, which finally results in the production of a quark–antiquark pair, and thus turning the initial hadron into a pair of hadrons instead of producing an isolated color charge. It is quite interesting to note that the color confinement is well established from lattice QCD calculations and decades of experiments, though it has been quite difficult to prove it analytically. It is also important to note that a quark is a type of elementary particle and a fundamental constituent of matter; and the quarks combine to form composite particles called hadrons, the most stable of which are protons and neutrons. Due to the color confinement, quarks can not be directly observed or found in isolation, and can only be found within hadrons, which include baryons such as protons and neutrons, and mesons. This is why the quarks have been mainly studied by observing hadrons.

(ιι) Asymptotic freedom, which in fact is a steady reduction in the strength of interactions between quarks and gluons as the energy scale of such interactions, thereby decreasing the corresponding length scale. It is important to note that for discovering the asymptotic freedom of QCD by David Gross and Frank Wilczek, in the year 1973, and independently by David Politzer in the same year, Noble Prize in Physics was shared by them in the year the 2004. SciDAC-2 Software Infrastructure for Lattice Quantum Chromo Dynamics (QCD) has drawn the attention of researchers [9,10]. Joo Balint [10] has presented the important work carried out by the Software Infrastructure for Lattice QCD. The Quantum Chromo Dynamics is the theory of the strong force, which describes the binding of quarks by gluons to make particles such as neutrons and protons. It may be noted here that the strong force is one of the four fundamental forces in the Standard Model of Physics, the others being Gravity, Electromagnetism, and the Weak force. The designing aspects can be studied by following the approach of Holmgren Don [9], and considering the numerical simulation of Lattice QCD. In fact, the QCD action, expresses the strong interaction between quarks mediated by gluons expressed as:

$$S_{Dirac=}\bar{\psi}(D^*+m)\psi \qquad (1)$$

$$D^*\psi = \sum_{\mu}\gamma_{\mu}(\partial_{\mu} + igA_{\mu}(x))\psi(x)$$

Where the Dirac operator ($\mathbb{D}$) is given by: (2).

It can be visualized that the Lattice QCD uses discretized space and time, and as given in the literature, a very simple discretized form of the Dirac

Operator is:

$$D^*\psi(x) = \frac{1}{2a}\sum_{\mu}\gamma_{\mu}[U_{\mu}(x)\psi(x+a\hat{\mu}) - U_{\mu}^{\dagger}(x-a\hat{\mu})\psi(x-a\hat{\mu})] \qquad (3),$$

Where a is the lattice spacing, and (x) is a quark, which depends upon ψ(x + aμ) and the local gluon fields Uμ. Clearly, ψ(x) is complex 3 × 1 vector, and the Uμ are complex 3 × 3 matrices.

It has now been well understood that for achieving the desired results, the Lattice QCD codes (MILC, expressed by the MIMD Lattice Computation Collaboration; Chroma using C++ and running on any MPI machine; and CPS using C++ and running on QMP machine) require (i) excellent single and double precision floating point performance, in which it has been observed that the majority of Flops are consumed by small complex matrix-vector multiplies – SU [3] algebra formulation; (ii) High memory bandwidth, which in fact has been observed to be the main problem; and (iii) Low latency, high bandwidth communications, which are found to be implemented with MPI or similar message passing APIs, and associated with clusters like Infiniband, Myrinet, and gigE mesh. It has to be noted that (i) Bridge++ is a code set for numerical simulations of lattice gauge theories including QCD; and (ii) according to the object-oriented design, the code is described in C++ programming language. Thus the designer is faced with a daunting task of taking all these points into consideration, which require not only great skill and experience on his part, but also help from computers. The Lattice QCD computations require multicore optimizations, automated workflows, reliability and fault tolerance, and visualizations. Lattice QCD requires computers consisting of hundreds of processors working together via high performance network fabrics.

QCD is the theory of the strong interaction, in the form of a non-abelian gauge theory invariant under SU [3]; and therefore, (i) The interaction is governed by massless spin 1 objects called gluons; (ii) Gluons couple only to objects having color, implying quarks and gluons; (iii) There are three different charges i.e., colors: red, green, and blue. In contrast to the fact that in QED there is only one charge i.e., electric charge; (iv) There are eight different gluons, which can change the color of a quark but not its flavor by exchanging glucon, as a red u-quark can become a blue u-quark; and (v) Due to the fact that gluons have color, there are couplings involving 3 and 4 gluons.

It has been observed that the SU [3], non-abelian nature of QCD leads to many interesting results like: (i) Quarks are confined in space, as a result of which a quark can not be seen unlike an electron or proton (ii) All particles (mesons and baryons) are color singlets, and in the quark model the D++ consists of 3 up quarks in a totally symmetric state, and something else is needed to make the total wave function anti-symmetric; (iii) Asymptotic freedom: In fact, the QCD coupling constant changes its value (meaning runs) dramatically as function of energy, which results in the quarks appearing to be free; and (iv) Though in principle, the masses of mesons and baryons can be calculated using QCD, it is very difficult to calculate any thing with QCD.

The main difference between QED and QCD is that QED is an abelian gauge theory with U [1] symmetry, and QCD is a non-abelian gauge theory with SU [3] symmetry:

$$L = \bar{\psi}(i\gamma^u \partial_u - m)\psi + e\bar{\psi}\gamma^u A_u \psi - \frac{1}{4} F^{uv} F_{uv} \quad (4),$$

Where m=electron mass, γ =electron spinor, $e\bar{\psi}\gamma^u A_u \psi$ is the electron-g interaction, Au=photon field, and Fuv=¶uAv-¶vAu/; and

$$L = \bar{q}_{jk}(i\gamma^u \partial_u - m^q) q_{jk} + g(\bar{q}_{jk}\gamma^u \lambda_a q_{jk}) G_u^a - \frac{1}{4} G_{uv}^a G_a^{uv} \quad (5),$$

Where m^q =quark mass, j=color [1-3], k=quark type [1-6], q=quark spinor. $g(\bar{q}_{jk}\gamma^u \lambda_a q_{jk}) G_u^a$ is the quark-gluon interaction, and $\frac{1}{4} G_{uv}^a G_a^{uv}$ is the gluon-gluon interaction (3 g and 4 g). However, for both QED and QCD the effective coupling constant (a) depends on the momentum or distance scale, and it is evaluated as:

$$\alpha(p^2) = \frac{\alpha(0)}{1 - X(p^2)} \quad (6)$$

Where a [0]=fine structure constant »1/137. For the case of the QED, it can be shown that:

$$X(p^2) = \left(\sum_{i=1}^{N_f} \left(\frac{q_i}{e}\right)^2\right) \frac{\alpha(\mu^2)}{3\pi} \ln\left(\frac{p^2}{\mu^2}\right) \text{---} \quad (7)$$

Where X [p2]>0, Nf is the number of fundamental fermions with masses below ½|p|, and m is the mass of the heaviest fermion in the energy region under consideration. It has to be mentioned here that the situation for QCD is very different than QED. Because of the non-abelian nature of QCD, it can be seen that

$$X(p^2) = \frac{\alpha_s(\mu^2)}{12\pi} \ln\left(\frac{p^2}{\mu^2}\right)[2N_f - 11N_c] \quad (8).$$

Where Nf is the number of quark flavors with masses below ½|p|, m is the mass of the heaviest quark in the energy region under consideration, and Nc is the number of colors [3]. It can be seen that for 6 flavors and 3 colors 2Nf-11Nc < 0, and therefore, a (p2) decreases with increasing momentum or shorter distances. Thus, it is very surprising result that the force between quarks decreases at short distances, and increases as the quarks move away from each other. Another important result is the fact that gluons carry color and couple to themselves, which leads to asymptotic freedom. In fact, the strong force decreases at very small quark-quark separation and increases as quarks move away from each other. It has been established that the asymptotic freedom leads to quark confinement.

RESULTS

Some of the important results in the fields of Lattice QCD-D meson semileptonic decay amplitudes; and Computational Cosmology have been given below:

Lattice QCD - D meson semileptonic decay amplitudes

Some interesting studies [10] on D meson decay constants, and D meson semileptonic decay amplitudes have already been carried out. These results have been reproduced; and technically discussed below: The figure shows the results of the variation of f+(q2) with q2/m2D × S in the form of the curves. Interestingly, the experimental results of Belle are very close to those of Lattice QCD by Fermilab (Fermilab is a member of the SciDAC-2 Computational Infrastructure for the LQCD project). The value of f+(q2) rises quite linearly from 0.75 tp 1.75 with q2/m2D × S varying from 0 to 0.45, So for achieving the desired D-meson semileptonic decay amplitudes for the Lattice QCD, the designer of the experiment has to choose the values of f+(q2) and q2/m2D × S carefully by studyimg the variation between them, separately for the various cases, and then doing the optimization (Figure 1).

Computational cosmology

Cosmolgy is a branch of Astronomy concerned with the studies of the origin and evolution of the universe, from Big Bang to today, and into the future, and thus is the scienctific study of the origin, evolution, and ultimate fate of the universe; and the laws of science governing these areas. Many interesting studies [11,12] have been made on this topic.

The Hubble Extreme Deep Field (XDF), as reported in the literature, has been reproduced below (Figure 2):

It is to be noted that this XDF was completed in 2012. Some galaxies are 13.2 billion years old, and there are 2 trillion galaxies. It has been observed that the High-performance computing (HPC) has proved to be an integral and indispensable part of cosmological research, and during the last 10-15 years has become one of the most important tools in explaining the most fundamental problems in cosmology. The huge data collected from various investigations has to be analyzed for cosmological information, and this is being done by the State-of-the-art cosmological simulations, requiring millions

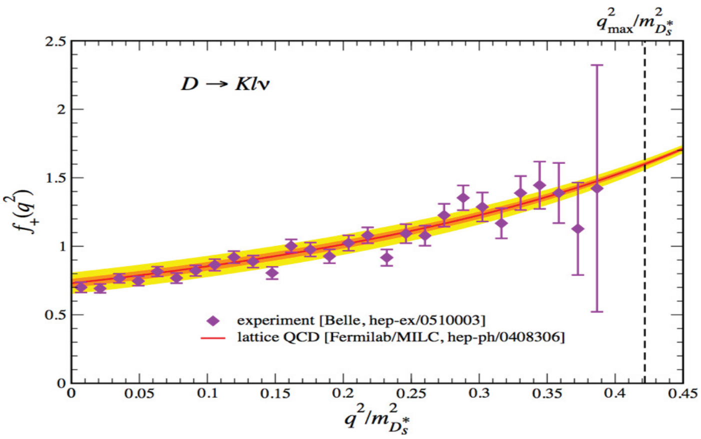

Figure courtesy: B alint Jo o, SciDAC-2 Software Infrastructure for Lattice QCD, Journal of Physics: Conference Series, 78 (2007) 012034.

Figure 1: D-meson semi-leptonic decay amplitudes.

Figure courtesy: Hubble Observatory.

Figure 2: The Hubble Extreme Deep Field (XDF).

of CPU hours of supercomputing time and tens of terabytes of storage. The Computational Cosmology MA has been created with the objective of making available the high-performance computing framework required for such investigations. In fact, this MA is a cross-cutting, science enabling MA, which interacts with various research MAs for helping them to achieve their goals.

It has to be appreciated that the modern state-of-the art cosmological simulations require more inter-communication between processes as compared to the Lattice QCD. Its magnitude can be judged from the fact that these simulations for certain sizes take even >1,000,000 CPU-hours, which require computational platforms with wide (multi-CPU), large-memory nodes. This requires very high class Performance Computing (HPC) support, and studies based on Astrophysics. Some of the Simulation of the cosmic web of dark mattandg, as reported in the literature, have been reproduced and can be clearly seen that the cosmic web of dark matter filaments and halos prepared by the Simulation based on advanced computing gives a very clear understanding of the filaments and halos (Figure 3).

DISCUSSION

Many new efforts are taking place for the advancement of Aerospace Industry by application of Advanced Computing. The virtual 2021 AIAA SciTech Forum [13] is going to be held, which will be a significant event for this industry. At present, collaboration and technical exchange is paramount to overcoming challenges and achieving stability. The 2021 forum is expected to explore the role and importance of Advanced computing in the Arrospace systems. The diversification of teams, industry sectors, technologies, design cycles, and perspective have led to many innovations. Also, courses on this are attracting Researhers e.g. ISU's Aerospace Engineering Program [14] offers research opportunities that go beyond traditional aircraft and spacecraft. Turbulence research, icing physics, aviation electronics, tornado simulation, and UAS formation flight control are only a few of the topics. In addition, applications of Advanced computing for cutting-edge research in nondestructive evaluation, computational fluid dynamics, wind engineering and experimental aerodynamics, guidance and control, and rotorcraft/UAS/MAV, turbine science and technology are being taught and explained.

Esposito et al. [15] have discussed that the mproving processes in a company start from a deep knowledge of the current context, of the needs for improvement and of the objectives to be satisfied; and that sometimes, traditional processes can benefit from a techno-organizational innovation that changes the way of work by introducing new routines and solutions. Esposito et al. [15] have characterized the service industry related to maintenance, repair and overhaul (MRO) by performance linked with the knowledge about the components involved. It has been emphasized that the emerging technologies and the need for enhanced competitiveness has led to transform and innovate this kind of industry, introducing changes in organizational and technological aspects; and the MRO processes are characterized by high variability, It has been reported that New Disruptive Computing & Networks organization will operate as part of Boeing Engineering, Test & Technology: and a new Disruptive Computing and Networks (DC&N) organization will develop computing and communications solutions for advanced commercial and government aerospace applications [16].

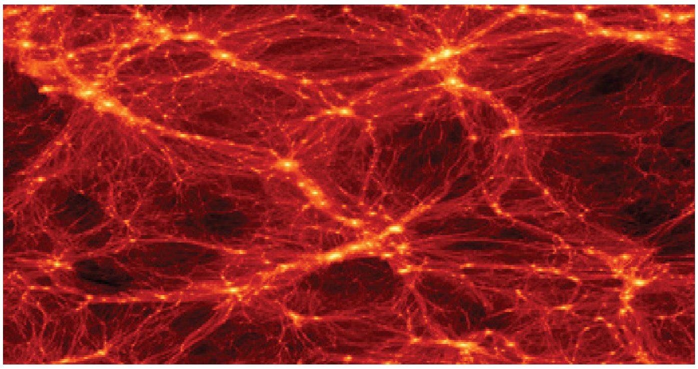

Figure 3: The cosmic web of dark matter filaments and halos.

The applications of Advanced Computing in Control Engineering in Aerospace Industry have recently picked up. It is interesting to note that Boeing has launched a new business tasked with researching and development of solutions in artificial intelligence (AI), secure communications and complex systems optimization for commercial and government applications. They have formed a group called Disruptive Computing and Networks (DC&N), for operating out of Southern California as part of Boeing Engineering, Test and Technology. Intelligent Flight Controls are being used for developing a flight control concept, using neural network technology for identifying aircraft stability and control derivatives, that allow optimal aircraft performance under a wide range of flight conditions. However, the challenge is to develop a learning neural network, which can update aircraft stability and control derivatives during flight, and in response to off nominal events of piloted flights. Also In Aerospace Industry,

CONCLUSION

Quantum Computing is showing great potential to solve computational challenges in aircraft modelling, simulation and many related problems, including speeding up aircraft design, debugging millions of lines of software code and resolving complex computational challenges. In addition, Educational Institutes and Research Agencies have been showing more interest in this field. Thus, it can be safely concluded that this field is on a firm, and evolving fast.

ACKNOWLEDGEMENTS

The author is grateful to Dr. Nand Kishore Garg, Chairman, Maharaja Agrasen Institute of Technology, GGSIP University, and Delhi for providing the facilities for carrying out this research work, and also for his moral support. The author is thankful to Dr. M. L. Goyal, Vice Chairman, Academics, for encouragement. Thanks are also due to Prof. V. K. Tripathi, Department of Physics, Indian Institute of Technology, and Delhi for useful discussions and various suggestions which have significantly improved the presentation of the paper.

REFERENCES

1. Davis FK. The Computer Establishment, Publisher: McGraw-Hill Osborne Media; English Language Edition 1982;269:279–280.
2. Kelly C. From Airline Reservations to Sonic the Hedgehog, A history of the Software Industry. Cambridge, Massachusetts: MIT Press, USA. 58;63.
3. ACM Digital Library. 2014.
4. Paean: An ACT/Inter-ACT Communication. Computer History Museum. Retrieved August 31, 2014

5. Company Background. Edison Design Group. Archived from the Original. 2014.

6. Thomas H. An Interview with Oscar Schachter (PDF). Minneapolis: Oral History Collection, Charles Babbage Institute, University of Minnesota. World Cat Entry. 2004.

7. Oliver G. Advanced Computing, FRA Visiting Committee. 2007.

8. Nain Chopra K. Technical Note on Advanced Computing Concepts with Applications in Particle Physics, Networking, Data Handling and Predictive Analytics, Atti Fond G. Ronchi, 2018;73;477-484

9. Don H. Lattice QCD Workflow Workshop, Fermilab, USA. 2006.

10. Joo B. SciDAC-2 Software Infrastructure for Lattice QCD. 2007;78:12034.

11. Bandyopadhyay MN, Bandyopadhyay R, Chatterjee S. The Mysteries Of The Universe - Where Fact is more Interesting than Fiction: A Book on Astronomy & Cosmology. 2020.

12. Peebles PJE. Cosmology's Century: An Inside History of Our Modern Understanding of the Universe 2020.

13. AAIA Sci Tech Forum. 2021,

14. Aerospace Engineering, Iowa State University Catalog: IOWA State University, USA.

15. Marco E, Mariangela L, Antonio M, Lorenzo Q. Innovating the maintenance repair and overhaul phase through digitalization. Aerospace. 2019;6:.53.

16. Boeing Launches New Organization to Unleash the Power of Advanced Computing and Networks in Aerospace, Chicago, USA. 2018.