Convergence: Commodity flight simulation and the future

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ABSTRACT

The development of commodity flight simulation, in the form of PC game technology, continues to advance at a rapid pace. Indeed, the software industry is now being driven primarily by the requirements of gaming, digital media, and other entertainment applications. This has largely been due to the commoditisation of computer hardware, which is apparent when considering recent trends in central processing unit and graphics processor development.

The flight simulation industry has benefited from this trend of hardware commoditisation, and will continue to do so for the foreseeable future. It is, however, yet to fully realise the potential for leveraging commodity-off-the-shelf (COTS) software. In this paper the opportunities presenting themselves for the next 25 years of flight simulation are discussed, as the aviation and games software industry's requirements converge. A SWOT (strengths-weaknesses-opportunities-threats) analysis of the commodity flight simulation software industry is presented, including flight modelling, scenery generation, multiplayer technology, artificial intelligence, mission planning, and event handling. Issues such as data portability, economics, licensing, intellectual-property, interoperability, developer extensibility, robustness, qualification, and maintainability are addressed.

Microsoft Flight Simulator is used as a case study of how commodity flight simulation has been extended to include extensive programmatic access to its core engine. Examples are given on how the base platform of this application can be extended by third-party developers and the power this extensibility model provides to the industry.

This paper is presented to highlight particular technology trends in the commodity flight simulation industry, the fidelity that commodity flight simulations can provide, and to provide a high-level overview of the strengths and weaknesses thereof.

NOMENCLATURE

AGL	above ground level
AI	artificial intelligence
AIAA	American Institute of Aeronautics and Astronautics
API	application programming interface
CIGI	common image generator interface
COTS	commodity-off-the-shelf, commercial-off-the-shelf
CPU	central processing unit
CRT	cathode-ray tube
FNPT II-MCC	flight and navigation procedures trainer, Type II formulti-crew cooperation training
FSX	Microsoft Flight Simulator, version 10
GFLOPS	billion floating point operations per second
GPL	gnu general public license
HLA	high-level architecture, US Department of Defense
HPC	high performance computing
IP	intellectual property
IT	information technology
LCD	liquid crystal display
LCoS	liquid crystal on silicon
MMOG	massively multiplayer online game
MSFS	Microsoft Flight Simulator
PC	personal computer
SDK	software development kit
SWOT	strengths-weaknesses-opportunities-threats
VATSIM	virtual air traffic simulation network
VFR	visual flight rules

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1.0 INTRODUCTION

1.1 Background

Since the days of the LINK trainer in the 1920s, flight simulation has developed primarily as a way of improving flight safety through better pilot training. The move from mechanical to electronic systems in the early 1960s enabled out-of-the-cockpit views to be more accurately represented, and flight dynamics to be simulated in more realistic ways. The 1980s and 1990s saw great advances in flight simulator technology, but was largely restricted to bespoke systems from specialist suppliers. A flight-simulator requires a high degree of computing power allied to a high resolution display system due to the high fidelity requirements in real time and the complexities of the flight mechanics calculations[1]. In the past this has inevitably led to a high purchase price of 0(millions) pounds. Recent advances in personal computer(PC) power, however, have narrowed the gap between high-end and desktop computing capability. In 1965 Moore observed that '*the complexity for minimum component costs has increased at a rate of roughly a factor of two per year*'[2], and that the trend would continue for the foreseeable future. Indeed, processor development has exceeded those initial predictions, with Moore's Law now accepted to translate into a doubling of processor power every 18 months, as illustrated in Fig. 1. Flight simulation has also, more recently, developed as a popular form of entertainment, with the increasing power and uptake of computers in the home.

The dramatic improvements and reduction in costs of PC technology have had important ramifications in traditional enterprise computing markets. An example of this is in the High Performance (or Super) Computing space. The trend in supercomputers has moved away from proprietary, or Big Iron, systems to clusters of PCs. The Top 500 Supercomputer list[3], compiled biannually, has seen a rise from no PC cluster-based systems in 1995, to over 70% in November 2006. This has not only been driven by the trends in commodity processor technology continuing to follow Moore's Law, but also the development and use of commodity software technology, such as Linux and Microsoft Windows™[4].

The commercial flight simulation industry is benefiting from the commoditisation of hardware, but has yet to fully realise the benefits of the commodity software stack. This is typical of the IT industry; advances in hardware architecture usually take several years to reach maturity as the software takes time to be able to take full advantage of the hardware. The demands of the consumer marketplace continue to push hardware and software development at an increasing rate. Indeed, it is this demand that is fuelling the entire IT industry, from processor and graphics development, to digital mapping and high-speed network capability. Intense competition in this marketplace is the reason that we are seeing such huge advances in computing hardware. The effect this has had on the technical computing market is dramatic, and has led to a shift towards using commercial off-the-shelf (COTS), sometimes also referred to as commodity-off-the-shelf, systems for tasks that were previously undertaken using bespoke systems. Current desktop PC processors, and even consumer games consoles, are capable of several billion floating point operations per second (gigaflops). Improvements in networking hardware, from Ethernet, through to Gigabit Ethernet and low-latency, multi-Gigabit network interfaces such as Myrinet[4] and Infiniband, enable PCs to be clustered together into tightly-coupled high performance computer systems.

While advances in desktop processor and networking have had a major impact on the HPC market, the flight simulation market has also been affected by advances in visual display system technologies in recent years. In order to generate out-of-the cockpit views, collimated mirror systems were developed so that an infinite depth-of-field could be well represented using cathode ray tube (CRT) technology. CRT systems have now been largely superseded by liquid crystal display (LCD) and digital light processor (DLP) projectors, which have become commonplace in office and educational environments. Newer liquid crystal on silicon (LCoS) high contrast, high-resolution projectors are now reaching maturity and are being used for flight simulation, and are permeating the home entertainment market for high-definition television applications. As the competition and rate of progress in the PC and workstation graphics card markets has increased, so has the attrition rate of manufacturers. As hardware for flight simulation has become more affordable, the industry has adapted to take advantage of these developments; for example, partnering with leading consumer graphics card vendors.

1.2 Flight simulation industry

The commodity flight simulation industry is based around an economic model developed for home entertainment (games) software. Pricing within the games market is set within a competitive environment. The *sell it cheap, stack it high* approach must recover the development costs and provide sufficient profit margins. In the case of a long-running product line, the profits

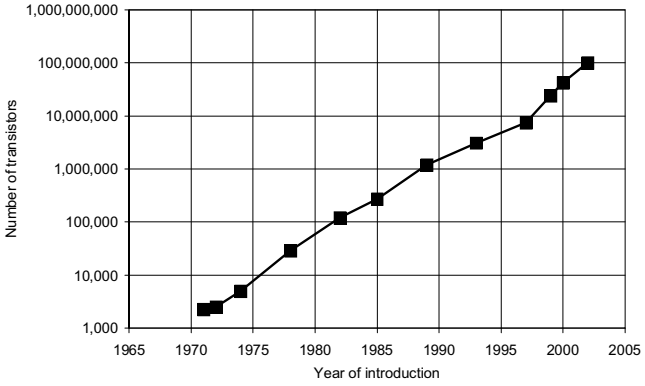


Figure 1. Development of desktop computer central processing units over time (source: Intel Corporation).



Figure 2. COTS-based FNPT-II MCC simulator of an Avro Lancaster bomber.

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should be sustainable over the lifespan of several product versions.

The PC entertainment flight simulation marketplace has been cyclical over the past two decades. Typically this software falls into combat and non-combat products. There are currently few general flight simulators in the non-combat category, as the market has consolidated over the past decade. The market leader is the Microsoft Flight Simulator series (MSFS)[5], which has been under development for 25 years and is the subject of a case study presented in Section 3. Another popular commercial product is X-Plane, which has more recently been developed by a small company, Laminar Research. Flight Gear is a community-based project that uses an open source development model[6]. These three products represent different development and economic models which are discussed in this paper.

1.3 Capability

A recent demonstration of the capability, and flexibility, of an entirely COTS-based flight simulator was a recreation of the famous Dambusters raid of 1943. A flight simulator was designed to recreate specific Avro Lancaster bomber missions of 617 Squadron's raid on the Ruhr Valley dams in Northern Germany during World War 2[7]. The simulator met the requirements for a joint air regulations flight and navigation procedures trainer, Type II for Multi-Crew Co-operation training, FNPT II-MCC[8]. This placed several stringent requirements on the simulator that were unable to be met by other available flight simulation facilities within the United Kingdom at the time:

- the Lancaster bomber is a seven-crew aircraft. All crew stations had to be simulated within an ergonomically accurate physical environment;
- the flying characteristics and instrumentation of the Lancaster bomber had to be reproduced accurately;
- low-level visual flight rules (VFR) scenery for below 100ft AGL for an area covering 300,000km^2 over UK and Northern Europe had to be faithfully represented;
- customisability of the simulator to ensure the presence of realistic key landmarks, including dams circa 1943, was necessary.

The system developed for this project consisted of five PCs driving twelve displays, running MSFS and additional off-the-shelf third-party software to provide scenery, aircraft and networking capability[9]. By building a full-size replica of the Avro Lancaster, all seven crew stations could be accurately represented (pilot station shown in Fig. 2). What is notable about this simulator is that it was built entirely using COTS hardware and software, at low cost of (£10,000), over a period of two weeks[7].

1.4 Structure of paper

The aim of this paper is to analyse the characteristics of the consumer entertainment flight simulation industry, and how these may provide benefits to the commercial aviation industry. In Section 2 a generic SWOT (strengths-weakness-opportunitiesthreats) analysis is presented. In order to highlight many of the topics described in the SWOT analysis, Section 3 describes how one popular entertainment flight simulation product, Microsoft Flight Simulator, has developed over a period of 25 years, and how its current architecture is exploited by third-party developers. Section 4 is a discussion of the synergy between the consumer and commercial flight simulation industries. Some concluding thoughts are presented in Section 5.

2.0 SWOT ANALYSIS: STRENGTHS, WEAKNESS, OPPORTUNITIES AND THREATS

In this section we present an analysis of the key characteristics of commodity flight simulation software, or games, with reference to application within the commercial aviation industry.

2.1 Strengths

The computer games industry has grown substantially in the last few years, and is now worth over $28 billion globally per year, of which flight simulation games are a fraction. Competition is increasing and there has been consolidation within the industry as research and development costs have increased. There has been a move to standardise on gaming engines that are licensed for different products, due to the costs associated with continually developing them in the face of new technology. Large teams of developers are now required, with product development costs running into millions of dollars in some cases, representing a significant level of ongoing commitment.

The demands of the consumer gaming industry place a great emphasis on advances in technology, and are largely responsible for fueling ongoing hardware development. To meet market demands, new technologies are brought to market in very short timescales. Game developers must predict, at design time, what the end user's platform will be when the product is finished. This has traditionally been based on tracking Moore's Law, although this is becoming less reliable as processors reach physical limits. Current trends in multicore processor architecture aim to address this, and challenges for developers to harness this new approach are many. This is driven by the games console market, such as the Xbox 360 and Playstation 3 machines which feature multi-core central processing units, with the latter capable of over 200 billion floating point operations per second (GFLOPS). The development of graphics cards as more general-purpose parallel processing units provides scope for greater physics calculations to be offloaded from the main CPU, with the current generation featuring 128 separate processor cores capable of over 500 GFLOPS (peak). The application programming interfaces (APIs), such as Microsoft DirectX version 10, allow developers to readily exploit the graphics hardware (Fig. 3). In terms of software development, consumers typically demand continuous improvement on one-two year timescales. There is a strong application pull, coupled with a strong technology push. It is vital for game developers to keep in step with technology in order to stay competitive. This continued trend of technological advancement is a key characteristic of the commodity gaming industry, and provides great leverage to other related industries.

For a number of larger game products, including flight simulators, the ability to extend the product is becoming increasingly important. The games themselves are seen as platforms which third-party developers can extend. End user customisation is seen as an important factor to enhance the product's appeal. Such extensibility is typically well documented in the form of software development kits (SDKs) that are supported by the vendor. The third-party community helps to push the product between version upgrades, and can help to shape product development.

In order for games to be accessible, considerable effort is given to the design of the user interface. Best practice from desktop operating system and general application development, including extensive usability testing, is applied to ensure that software meets user requirements. This extends to in-game mission planning and briefings, which must be managed in a consistent and user-friendly way. The emergence of multiplayer networked gaming has led to the development of systems for managing communities of users which could prove useful in pilot training systems. For example, the TrueSkill Bayesian ranking system developed by Microsoft

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Figure 3. Microsoft Flight Simulator X.

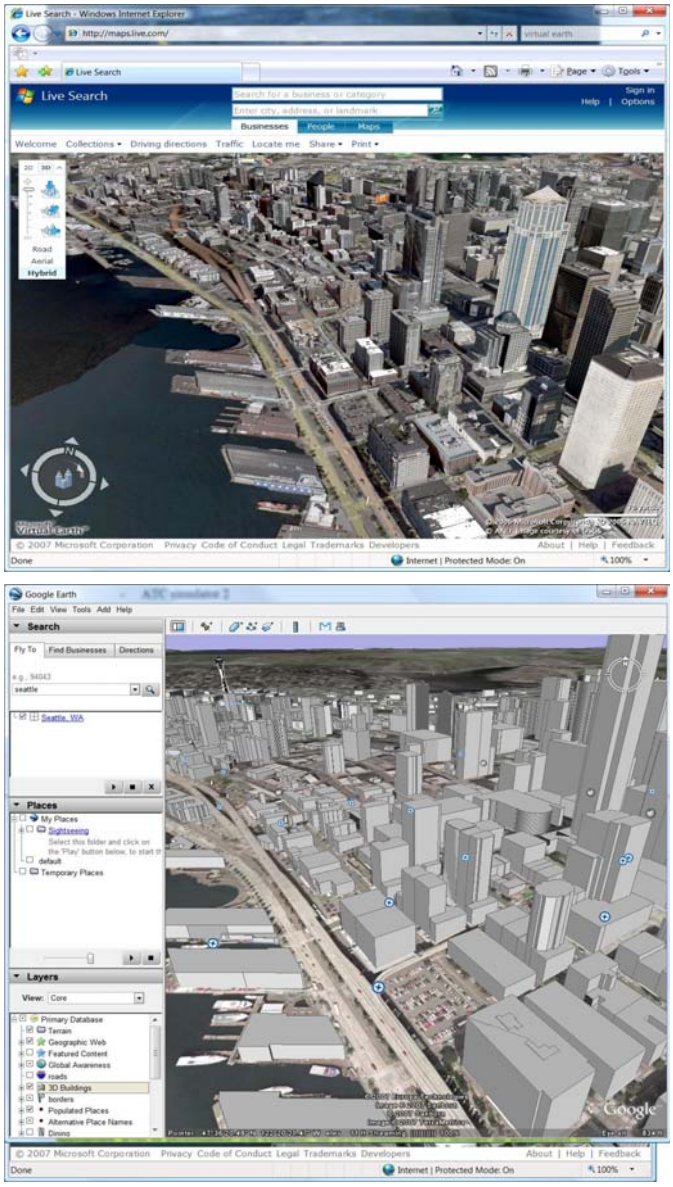


Figure 4. MSN Virtual Earth (top) and Google Earth (bottom) views of the Seattle waterfront.

Research[10] is used on the Xbox Live gaming network to provide real-time rankings of thousands of players worldwide.

Artificial intelligence (AI) is an area of research that has direct application in flight simulation. For example, air traffic control simulation with AI controlled aircraft is now an embedded feature in some products. Implementation of such capability is non-trivial but is demanded by consumers, and has wide application across other gaming genres. The development of multi-player networked gaming, including massive multiplayer with potentially millions of players, is one of the key areas of expansion in the consumer industry. An example of a large, battlefield environment is WW2 Online[11], which is a persistent combined arms simulation of the Second World War that can currently handle several thousand players simultaneously on a regular basis. The development of online gaming environments is a focus of the consumer games industry, and is an area that the military is embracing. For example, America's Army[12], developed since 1999 as the official US Army game, provides a multiplayer ground soldier battlefield environment and was developed as an effective way of providing information about the US Army and its doctrine, with a view to public education and recruitment. The total project cost is estimated at $7·5 million, and it currently has over eight million registered users (2007). While this may seem expensive, it is estimated that it is saving the US Army $700 million – $4 billion per year in terms of recruitment and training expenditure[12]. As an ongoing project additional game components are being added, such as Special Forces training and operations, and US Army Aviation. In terms of informing the public about military technology and doctrine, games can be exploited to perform this role in an extremely effective way.

2.2 Weaknesses

The applicability of entertainment flight simulation software for aviation use is limited by certification issues. In general this is not done, as certification is concerned with the entire hardware and software package, being largely dependent on the former. The fidelity of mathematical models and flight data is a key part of the certification process for validating the simulator system, and is often not the focus of software aimed at the entertainment market. This formal validation of flight models can be a significant cost for a certified flight simulator, though for some COTS based simulation software this is indeed possible. In some cases certification has been achieved, although it requires a flight simulation integration company to obtain the required certification of the complete simulator system. This decoupling of the software and hardware could be seen as a weakness.

The focus of entertainment software is on providing a good gaming experience, and is therefore not always targeted at realism. This managed reality approach is important to ensure widespread appeal, but is contrary to the requirements of the aviation industry. It can be thought of as a part-task trainer versus full simulation approach, with the perception of reality being the key differentiator. Consumers are, however, becoming increasingly interested in improved realism. Hence there is now increased pressure to produce games that are credible, while balancing entertainment versus non-entertainment requirements.

Due to the principal target market for games, a wide variety of hardware support is required, making it difficult to simultaneously support old and new technologies. Given that product lifecycle times are typically one to two years, this hardware compatibility issue is a major one. Developments can be hindered by requirements for backwards compatibility. This rapid refresh cycle also brings into question maintainability issues over the deployed lifespan of a solution. Longevity and long-term support of systems over five-to-ten year and greater timescales is an issue with all COTS solutions.

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2.3 Opportunities

There are many opportunities for the aviation and commodity flight simulation industries to work together, as there is a convergence of their goals[13]. The economies of scale of the games market means that it can provide an avenue for funding research and development. A recent example of this is MÄK Technologies, which marketed an M1 Abrams tank game (Spearhead) in order to prove its Department of Defense high level architecture (HLA)[14] This HLA implementation is now used across its SIMinterNET family of products, and Spearhead II is a standalone product that is in use by the United States Army. The reason cited for this approach was that the economics of the games market allowed the company to prototype the underlying technologies in an affordable way. Conversely, it may be possible for aviation projects within the games industry to help fund entertainment software.

As fidelity increases in games and simulation software, so does the cost of producing assets such as scenery and objects. This is partly responsible for the consolidation being seen in the gaming industry as production costs rise into millions of dollars. Reconstructing three-dimensional landscapes with photo-realistic textures is becoming a major cost in many games, and in flight simulation software. The availability of data for consumers using such services as Microsoft Virtual Earth and Google Earth (Fig. 4) is changing the marketplace. As these services mature, it is apparent that there may be a place for them in both entertainment and aviation flight simulation solutions. The emergence of common toolsets and data formats for manipulating and managing scenery data in particular is an area of commonality that may be worth exploiting. This extends to the sharing of objects, such as aircraft and building models, which take considerable time and effort to develop.

Consumers are demanding more realism in their games, which is driving hardware and software development. The advent of multicore processors and co-processing to perform physics calculations, described in section 2.1, opens up new avenues for exploitation. The ability to perform more real-time computations for flight, sensor and effects modeling is being used to enhance current products. This quest for realism is now an established part of the gaming roadmap, and has synergies with the needs of the aviation industry. In terms of flight modeling, the scope for commonality between entertainment and aviation implementations, perhaps through standards[15,16], could yield benefits for all by providing portability between systems.

The emergence of strong developer and user communities around commodity flight simulation families means that a considerable number of add-on applications, and content, is being produced. This can be particularly niche in its scope, but there is sufficient variety and demand that the long-tail economics remain attractive. This economic model can lead to small start-up companies with specialist skills that could be useful to the aviation industry. The diversity of this community is immense and is a breeding ground for innovation. The internet and worldwide web provides both a new distribution and collaboration fabric that can be exploited.

2.4 Threats

There are a number of threats to the exploitation of commodity flight simulation to the broader aviation industry. Intellectual property (IP) is an issue that must be managed with any sharing of data and services. Different licensing models for managing IP may be required to fully capitalise on the opportunities presenting themselves. New business models that can take into account the different cultures and characteristics of different industries must be developed; for instance, resolving market segmentation issues, between the high volume, low cost consumer products and bespoke, customised solutions. Creating businesses that can thrive in both of these markets may be challenging, but is achievable.

The qualification and certification of commodity-based flight simulation systems is possible, but is reliant on a system integrator who is able to take on the certification responsibility. This raises the question of liability, and how a software supplier is indemnified in such situations. The robustness of commodity flight simulation systems for continuous flight training use is reliant on the combined hardware and software setup, and hence the system integrator. The capabilities of commodity flight simulation are improving at a rapid pace, with potential for exploitation within the aviation industry. The response from the more established competition to this prospect is uncertain, although it is hoped that the opportunities will be embraced in the same way that commodity hardware is becoming the norm.

3.0 CASE STUDY: MICROSOFT FLIGHT SIMULATOR

In order to demonstrate how the consumer flight simulation software industry has developed, a case study outlining some of the capabilities of the latest version of the market-leading Microsoft Flight Simulator product (FSX) is discussed, driven primarily through a flexible and powerful extensibility model. This overview is intentionally brief in nature, and there are numerous other scenarios, products and technologies that are available in the market today[6, 13] that have similar characteristics to this particular example.

3.1 History

In 1975, Bruce Artwick was working on his master's thesis in Electrical Engineering at the University of Illinois entitled, 'A versatile computer-generated dynamic flight display'[17]. This paper demonstrated that the computers of that day could not only handle the mathematical computations required for aircraft simulation routines, but that they could also generate graphical images as a way to provide visual feedback to the user.

This work provided the strong roots which continue to support the Microsoft Flight Simulator (MSFS) product, with the motto 'As real as it gets' still being the driving mission statement for over 25 years of evolutionary development. Unlike most high-end, commercial level simulation systems that narrowly focus on accurate simulation of particular scenarios, MSFS focuses on accurate simulation of reality on a much larger scale, including the macro-simulation of planetary weather, globally accurate terrain and navigation, and support for realistic representation of a multitude of different types of flight vehicles.

In addition, the fundamental platform architecture has been paramount to its success in the marketplace. An extensive software development kit (SDK) has been a foundational element since the product's inception, providing a means for the community to contribute to the overall Flight Simulator ecosystem with both application (programmatic) and content (modelling, imagery, data) add-on components.

The demanding nature of real-time, interactive simulation requires that the software take advantage of every means possible in the graphics, networking and CPU utilisation hardware interfaces. The throughput of terrain data alone requires extensive utilisation of multi-core processing power to achieve the fluidic frame rates necessary to maintain the impression of flight.

3.2 Community

With each release of MSFS we see a gain in both popularity in and customer engagement with the various community based organisations in existence. The areas of interest include add-on development, vertical interest community organisations and even virtual airlines run in strict accordance with real-world airline operations.

The advantage this provides the newcomer is invaluable; there are literally thousands of 'experts' willing to help newcomers. Forums,

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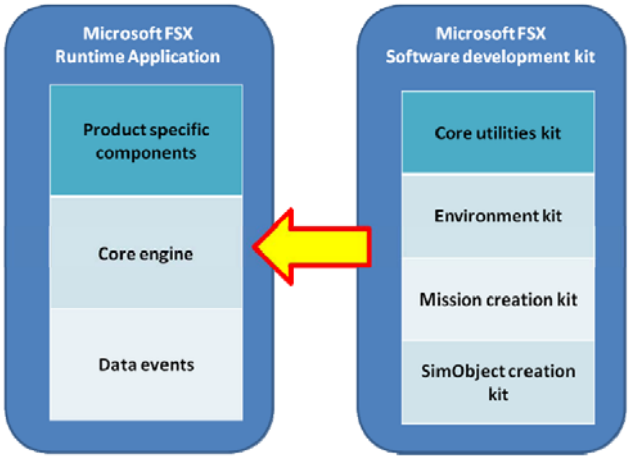


Figure 5. General arrangement of Microsoft Flight Simulator Software Development Kit.

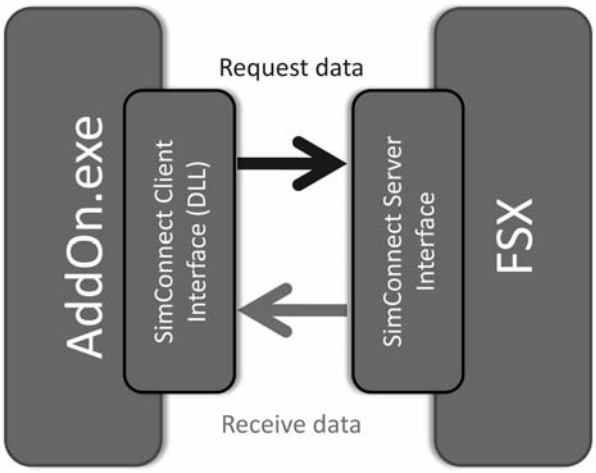


Figure 6. SimConnect communications infrastructure.

web logs (blogs) and even virtual universities are available to learn how to use or enhance the product experience. The extensibility that the MSFS platform provides has resulted in a plethora of professional add-on developers, and has stimulated a cottage industry around the development, sales and distribution of professionally developed add-on software products.

3.3 Software development kit

The software development kit, or SDK, is a collection of documentation, tools, samples, code snippets and plug-ins that allow a myriad of add-ons to be developed to work with Microsoft Flight Simulator X (FSX). The SDK is broken down into four primary kits targeted at a general area of add-on development (Fig. 5): Core utilities kit; environment kit; mission creation kit; and the SimObject creation Kit

Each kit contains the methods, procedures and techniques used to generate, for example, add-on scenery. Third-party developers are typically experts in one type of system or another; rarely does one person combine the knowledge and/or experience necessary to build multiple quality add-ons. Given this complexity and volume of information, it is not feasible to go into detail on every aspect of the SDK. Rather, the focus of this paper is on the SimConnect SDK, a part of the first core utilities kit, as this is the primary means by which add-ons can get access to and execute data inside of FSX. It is left to the reader to become familiar with the other components of the SDK[18].

3.3.1 SimConnect

The SimConnect API provides two-way communication between FSX and third-party applications. It is based on a client – server Architecture, incorporating a Winsock (Windows Sockets) communications protocol to allow the third-party client application to communicate with the internal flight simulator server via a standard network interface. The mode of communication is considered asynchronous, providing some advantages over the use of synchronous communications (Fig. 6):

- safe for use in multi-processor or multi-threaded applications;
- more efficient use of processing cycles
- server application stability.

The basis of establishing communications is via a publish/subscribe method. Essentially, the client requests a data packet or sends an event, and the server will process that request at a time commensurate with the priority level of the request. This could be at visual frame time, simulation frame time, or any lower frequency as directed by the client application. The process is, however, considered asynchronous, as control of the processing time is never handed over to the client.

This application program interface (API) framework has been designed to support both Native (C, C++, Delphi) programming languages, as well as the managed .NET languages (C#, VB.NET, JavaScript). This allows a programmer the ability to develop applications using the programming language he or she is most comfortable with, likely resulting in shorter development cycles and better code stability.

The data, events and flight simulator system calls available via the SimConnect interface support the vast majority of the required data access demanded by third-party applications. Periodic updates of the SimConnect interface have been designed to ensure continued support of the interface.

3.4 SWOT

In this section a SWOT analysis is performed specifically on FSX, in the context of Section 2 above.

3.4.1 Strengths

As described above, the strengths of this particular product can be broken down into the following:

- long history of evolutionary development;
- built-in extensibility model;
- detailed, powerful and flexible software development kit (SDK);
- programmatic access API framework supporting both Native and Managed applications;
- strong community presence and support network.

3.4.2 Weaknesses

Though touched on briefly early in this paper, the primary weaknesses of an application such as FSX are:

- **Certification**. FSX is not allowed to be used to log actual-training hours as part of any certified pilot training program.

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The end user license agreement (EULA) specifically states that the product is to be used for '…entertainment purposes only.'

- **Fidelity**. The design of FSX prioritises the accuracy of components as they relate to the 'out-of-the-box customer experience. This means that a great deal of attention is placed on a particular set of aircraft systems, certain locations in the world, and foundational core engine components that contribute to the primary scenarios targeted for the gaming consumer. This leaves the vast majority of highly accurate simulation components, global data and imagery and other components to be designed and developed by third-party add-on providers.
- **Backwards Compatibility**. Due to the immense customer base and strong product history, the FSX customer demands that add-ons built for one version of the product continue to work in the next. This can be a burdensome requirement, sometimes slowing or hindering the development of new systems that would otherwise completely break the compatibility of code and assets from one version to the next.

3.4.3 Opportunities

The MSFS product is under continuous development; as each version is released, the gap closes between the virtual simulated reality it provides and the real physical world. However, reality is something that can only be approximated – and there are many ways in which a closer and much more extensive approximation can be improved:

- **Economies of Scale**. MSFS is developed in accordance with what the mass market sales volumes will support. This allows for long development cycles (two-three years), focus on cutting edge graphics technologies, and small-scale incubation efforts that can be investigated in concert with the production development cycle.
- **Cross-Group Collaboration**. MSFS is in a unique space in the software industry: being part of the Microsoft Corporation. There are numerous other internal organisations leading the way in software innovation, and the opportunities for collaboration include working with Virtual Earth, Streets and Trips, Microsoft Research and other product groups in Microsoft Game Studios to maximise the value of application and content development across the entire company.
- **PC Technology**. It is evident that PC processor technology is going to continue to evolve quickly in the realm of multicore and multi-processor availability. As FSX is CPU bound, or limited in its real-time ability by the availability of CPU cycles, a prime opportunity is to continue to take advantage of proper software scheduling of threads, fibers and filaments in the various sub-systems. Additionally, the graphics processing units continue to gain ground in the interface to process matrices and other math-intensive operations as fast, if not faster, than a CPU.
- **Aftermarket Industry**. Although FSX has had a strong community and large collection of 'hobbyist' aftermarket add-ons, there has been tremendous growth over the last five years in the 'professional' aftermarket industry. This trend seems destined to continue, as the typical customer is not aware that this aftermarket industry even exists. As the technical and business talent continue to mature in this industry, along with the technological advancements in the SDK, the third party community will continue to provide value to the base MSFS platform well into the future.

3.4.4 Threats

The threats that exist today are not so much related to the success of MSFS in the marketplace, but rather to its future development.

- **Intellectual Property (IP)**. IP, as defined in the software industry, has continued to evolve in meaning. The changing nature of what is considered 'property' by someone as it relates to software or concepts has made it difficult, if not impossible, to ensure adequate protections are in place. Providing a robust and flexible extensibility model complicates this issue, as aftermarket developers must feel their assets are protected in the marketplace as well as those of Microsoft's. A great deal of time and resources are devoted to this issue in a typical development cycle, which is time that could otherwise be spent designing, prototyping or otherwise building an end product. As the software market matures, it is hoped that the significant efforts placed in this area will diminish.
- **Qualification**. The ability to utilise a software component for use in any certified training curricula is predicated on that software passing a rigorous suite of tests in concert with a specific set of hardware interface components. This 'combination' approach to certification means that the software alone cannot be certified. As Microsoft is not in the hardware business (at least as it relates to real-world aviation components), the onus will be on third party integrators to evaluate this product's ability to be part of any certificated program.
- **Competition**. The unique niche segment that FSX enjoys is no doubt in jeopardy of being populated with any number of competing products. Though the longevity and team skill set employed on the Microsoft team provides a strong bedrock that will be difficult to supplant, new products that come to market might take advantage of a 'fresh start' to the problem space. Small start-ups or even the large, established commercial simulation companies may take notice of the success of MSFS and attempt to enter into the entertainment simulation space. There is not much that can be done about this, except to continue to listen to the customer and build the best product possible given the time and resource constraints the business demands.

3.5 Examples

A few examples of FSX add-on applications and components are provided here for reference;

- the virtual air traffic simulation network (VATSIM) is a community run, large scale massive multiplayer online gaming (MMOG) system structured with real-world air traffic controllers and world-wide coverage for community flying[19].
- SimCharts by Jeppesen[20] plugs into MSFS and contains a worldwide terminal chart set that matches the Jeppesen NavData contained in Flight Simulator. SIMCharts allows users to sort, view and print real Jeppesen arrival, departure, approach and airport charts that thousands of pilots and airlines around the world use every day.
- Precision Manuals Development Group[21], run by former 747 Captain Robert Randazzo provides high fidelity add-on aircraft for MSFS, including the Boeing 737, MD-11 and 747-400 Queen of the Skies.
- FSDiscover[22] is a novel add-on that turns MSFS into a virtual sight-seeing guide, navigation tool and flight planner.
- HiFi Simulation Software's Active Sky[23] is an interactive, real time global weather system that plugs into MSFS, supporting phenomena such as hurricanes and wake turbulence.
- The TileProxy Project[24] provides a real time interface between MSFS and satellite terrain servers on the Internet. Most software components are released as open source under the GNU General Public License (GPL).

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Figure 7. Ship simulation rendered in Microsoft Flight Simulator.

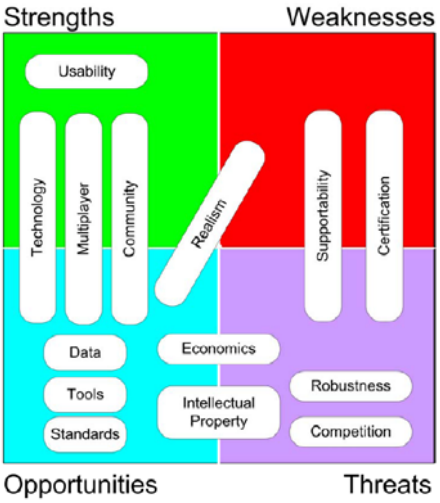


Figure 8. SimConnect communications infrastructure.

- Ship simulation via SimConnect. Current work at the University of Southampton involves modeling ship motion so that helicopter landing strategies can be investigated. Figure 7 shows a six degree of freedom ship model computed by its own dynamics software, being rendered in FSX via SimConnect.

4.0 DISCUSSION

In light of the SWOT analysis (Fig. 8) and examples presented in the case study, we discuss some potential avenues of development that may be beneficial for both the games and aviation flight simulation industries. These are, of course, subject to many of the licensing and intellectual property issues highlighted in Section 2.4.

There are many issues that arise from the convergence of markets. For example, the commoditisation of hardware in the flight simulation industry is now accepted as the norm, as it is an inevitable economic model. While overall there are new opportunities, existing organisations must adapt to take advantage of these. In the flight simulation market this is already happening, and is driven by market demands. What is interesting is the number of small companies who are able to enter the market with niche products at the boundary between consumer and professional systems. This is resulting in more market segmentation; there will always be requirements for high-end simulators, but there is now more scope for low- to mid-range part-task trainers at affordable costs, and hence opportunities to expand the flight simulation market significantly[25]. The labour situation is also changing, as many individual developers and small companies are able to provide technical skills that can be tapped by the industry. This is also happening in the television and movie special effects and post-production marketplace, due to the capability of COTS hardware and software.

The application of commodity flight simulation technologies to the wider aviation market has many scenarios which we explore here. As the target hardware platform is individual personal computers or laptops, portability becomes a key factor. While not necessarily possessing full flight control and cockpit system fidelity, the use of commodity software for portable part-task training is an attractive prospect. Taking advantage of the mission planning and usability aspects could lead to enhancements in current best practice. By leveraging the extensibility of underlying platforms, effective systems could be developed based on commodity software. The use of such systems for general aviation simulators is an interesting prospect[25], and a potentially lucrative market.

One of the key strengths of the games industry is the rapid level of technological development. The ability to capitalise on this is largely bounded by the ability of software vendors to implement new features. This is an area in which the gaming industry has a lead regarding commodity hardware, and is where collaboration could be of benefit. The aviation industry is already moving to COTS hardware, and the additional value by leveraging COTS software include a continuous upgrade path, potentially lower costs and shorter time to market. Stabilising on certain hardware platforms becomes an issue that must be addressed, however, in terms of supportability in the long-term.

The rapid development of network multiplayer capability within the gaming industry parallels efforts in the military simulation industry, with work being carried out on performance, peer-to-peer architectures and the impact of massively multiplayer online scenarios.

Perhaps one of the biggest opportunities is in the growth of publicly available data services. The deployment of significant web service offerings, such as Microsoft Virtual Earth and Google Earth, represents a shift in architecture towards network-based content; it is evidence of the commoditisation of content. The implications of this are far-reaching as the quality and quantity of the scenery databases improves over time. The availability and development of common standards and tools may be critical in enabling this to mature quickly. This also highlights the importance of a wide user and developer community which is an embedded part of this ecosystem. It mirrors the community that has formed around commodity flight simulators, with significant numbers of third-party suppliers offering a wide range of add-on products. The internet provides a low-cost distribution mechanism that supports long-tail economics, and a plethora of niche products. The evolution of the open-source model for software, such as FlightGear[6] and CIGI (common image generator interface[26]), provides one way in which community-driven projects can be driven forwards. This does, however, bring its own intellectual property and licensing issues that must be addressed.

The adoption of standards across the flight simulation industry is much needed to ensure portability and data re-use. If these standards can be applied to the entertainment software industry then there is great potential for collaboration and enhanced development. With the growth in research simulation, and the increase in number and complexity of networked simulation systems, carefully designed software and architecture standards are critical. For R&D departments and academia, low cost and rapid development are key; standards allow data and methods to be shared and re-used.

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Architectural standards, such as the widely adopted HLA, facilitate collaborative development and the interconnection of different simulators. When standards have been satisfied, and validation and verification have been documented the cost and development time of a trustworthy solution are reduced.

There are several possible modes of collaboration between the aviation and consumer flight simulation markets, and academia. A major difficulty in this arena, however, is the differing cultures of the aviation and consumer software industries[13]. These include differences in acceptable timescales, budgets, definitions of return-on-investment, competition within the marketplace, and longevity of in-service products.

Direct collaboration between companies, often under formal licensing agreements, is the most obvious partnership. This can include simply endorsing products, typically in order to gain credibility in the marketplace, and is often extended to include an exchange of technical information and cross-marketing opportunities. There are business and legal issues that must be considered, such as market segmentation, cross-licensing and reverseengineering of products. When such collaborations can, however, demonstrate tangible benefits to the both parties, within agreeable timescales and budgets, then the savings in terms of budget, time-to-market and long-term product development can be significant.

While the direct collaboration approach benefits individual companies in the short- to medium-term, more widespread initiatives may be more advantageous in the long-term to ensure that software costs do not spiral as customer requirements increase. For example, the development of standards for describing flight models may provide significant benefits to both the aviation and consumer industries[15]. It is such a standards-based approach that has been a key to the interoperability, platform-independence of the Internet as a whole. Some progress is being made in this area through the AIAA Modeling and Simulation Technical Committee[16] and this is a promising first-step towards realisable standards for the industry. By providing a well-defined format for describing flight model data, it will become easier to re-package the data for different end-users. In this way an aircraft manufacturer could re-sell a simulation model for both the high-end simulator market, while also providing data to drive low- to mid-range simulators, and games, to improve market awareness and generate additional revenue. While the direct implementation of any standard in existing applications could prove problematic, it would significantly aid the conversion of flight model data into proprietary formats. This could provide particular benefits for the general aviation simulator market, which is largely untapped at present but will undoubtedly grow significantly in the coming years[25].

In terms of driving forward development in a coherent way, academia is well positioned to provide a suitable vehicle due to its relative independence and as an established route for basic and applied research and development. The biggest issues arise from licensing and intellectual property, and here a cost-benefit analysis is required on a case-by-case basis for each application. The culture difference between the entertainment and aviation industries is perhaps the biggest barrier to progress, but one which is not insurmountable.

5.0 CONCLUSIONS

Having observed the trends in the related high performance computing market, it seems apparent that leveraging COTS technology, where possible, and moving towards common standards provides a viable environment in which the flight simulation industry can prosper in the future. As software costs continue to rise, it is in this area that the largest gains can be made by working together. In this paper a generic SWOT analysis has been presented that highlights how commodity flight simulation software may be applicable to the aviation industry, summarised in Fig. 8.

Microsoft Flight Simulator (FSX) has been used as a case study to show how an entertainment-focused product has developed over a period of 25 years into a sophisticated software platform. A separate SWOT analysis of FSX has also been presented. In particular, strengths and weaknesses have been explored, with opportunities identified that may be exploited to help ensure sustainability in both the consumer and commercial flight simulation industries as software development costs continue to rise. Threats to exploitation have been identified, so that the two industries can focus on countering them, to their mutual benefit. It is hoped that this paper will act to stimulate debate and foster links between consumer and aviation industries, in an effort to capitalise on the significant benefits that may be realised through closer collaboration in the next 25 years of flight simulation, and beyond.

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