MOTION AND EMOTION

THE DRIVE TOWARDS A PERSONAL SIMULATOR

SYNOPSIS.

The lecture provides an overview and analysis of recent developments in low cost simulation equipment, leading to a discussion on their social and commercial implications.

During the last ten years a number of different simulation products have been developed in the U.K. the USA and Japan. Several of these products are described and the interesting differences are discussed. The technical and commercial problems associated with the development and exploitation of low cost simulators are analysed with respect to display, motion system, computing resource and supporting software. The many applications for entertainment simulators are reviewed.

An overview of current work is presented, including visual systems hardware and software, control system interactivity and the design of sensory interfaces. The demand for low cost simulation products in new applications is described, with an indication of market sizes.

The presentation ends with a warning of some dangers that are now beginning to emerge.

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INTRODUCTION

I am a Physicist and an Engineer who specialises in the co-ordination of technologies to produce new products, in industries ranging from cement manufacture to dairy farming, greenhouse control to electronic warfare. In my early years in industry after leaving University I built up a background in industrial electronics and control engineering which has been a very useful foundation for what I eventually needed to do.

After building the electronic warfare evaluation facility for Marconi at Stanmore I set up a company that began to market the first Super X simulator (now known as the Venturer) in 1985. The Super X organisation has recently become part of Rediffusion and my own company, DDL, now acts as design consultants for several companies world-wide.

In this lecture I have set out to provide an overview of the technology and market development of small simulators and to highlight interesting trends towards the evolution of a personal simulator.

BEGINNINGS

The idea of a simulator - in which an audience watches a film projection whilst being moved about - goes back for many years and includes a notable design by Douglas Trumbull of special effects fame; Doug's 1978 patent application is recognisably similar to the entertainment simulators of today.

The first successful commercial exploitation of the idea was probably by Doron Precision Inc. whose 12-seater SR2 was first sold as an amusement machine on motor screw jacks. Doron's main business is in driver training simulators but it occurred to them that an amusement machine might be devised by mounting a projector which plays a three minute film loop behind a rear projection screen, taking cues from the film sound track to drive electric screw jacks to provide some additional "interest" in the picture. The sort of pictures used were short excerpts from roller coaster rides, racing cars, bobsleighs and so on, in an exciting and constantly-changing sequence.

As might have been expected, the screw jacks could not stand up to the hard life of an amusement ride, which can operate for three out of every four minutes, twelve hours a day and seven days a week at full load if the ride is good. Indeed Murphy's Law says; "Equipment operating to maximum profit potential is most likely to break down at that time". (In 1984 Doron introduced a hydraulic version of the machine, with much-enhanced reliability.)

In 1981 a businessman called John Barman came into possession of a shop on Scarborough seafront as part of a financial deal and decided to exploit its location to promote an entirely novel form of entertainment. As a younger man John had worked in the USA as an assistant to Bill Moog and he was intrigued by the potential of simulators, for which Moog actuators were often employed. He also liked the idea of an amusement ride based on a moving cinema. John used a local coachbuilder to construct a long "fuselage" having 20 seats with a projection screen at the front and he employed a well known hydraulics supplier to provide the three rams, valves and hydraulic system. Of course, he used Moog control valves and Moog control amplifiers. A local engineering company built the structural framework and the bearings for the machine.

For visuals he used 8mm films showing a selected sequence of excerpts from science-fiction films (space flight and alien monsters), dubbed with a pseudo-American voice-over. The motion of the machine was originally produced by an operator using a joystick in real time for every ride, but the motion was later encoded on a synchronised audio tape.

The machine was labelled as having been built in "Dallas, Texas" and was surrounded with fairground light strings with a fairly raucous audio background and promotion videotape monitor running continuously. The passenger exit area incorporated a high velocity skirt blower for a "Marilyn Monroe" effect. The machine took, and I think it still takes, ten years later, a great deal of money. In 1982 John built a slightly larger machine at Coral Island, Blackpool but then decided to get out of the simulator business for the next five years whilst he concentrated on his U.K.

Benetton shops and the retail of tennis kit in Germany. (In 1985 I persuaded John that I should sell his Astrojets as part of the Super X range of simulators and the Blackpool machine was decorated in Super X livery.)

In 1984 Mitsubishi constructed a machine at an amusement park next to the Tokyo Dome which used a full six-axis motion base and a sixty-seat wide-screen cinema showing a space travel sequence (with English audio background and English credits). The machine is beautifully designed and built and is reputed to very reliable. But the power and bandwidth of the system is too small and the ride is "whimpish", with no vigorous motion effects.

In October 1985 the first really effective leisure simulators opened in the "Tour of the Universe" at the base of the CN Tower in Toronto. The "Tour" used two Rediffusion 6-axis motion bases fitted with 40-seater wide-screen cinemas showing 70mm film produced on Douglas Trumbull's "Showscan" system running at 60 frames per second. In July of the same year I had also built the first of the "Super X" 14-seater three-axis machines and installed it in the basement of the Dolphinarium in Brighton. Twenty or so Rediffusion machines are now operating in theme parks world-wide, particularly at Disney in Florida, California, Paris and Tokyo; and today more than 100 Super X machines are operating in 18 different countries.

Professional leisure simulators differ from the earlier machines in two very important aspects: -

1. They use more power (over 2 hp per person) and they have a wider bandwidth (more than 20Hz)
2. A great deal of expertise and computing power is applied to the precise synchronisation of motion cues to visual imagery.

The result of this power and precision is that important subconscious reactions are triggered in the human occupants and this is the very essence of the experience. The effect, as you will find if you have not yet ridden one of these vehicles, is that, apart from the first few seconds of the experience, no time or attention is spent thinking about the motion! All your attention is riveted on the visual display, which is seen as a window that looks out onto the immediate future experience towards which you rush headlong. In a true simulator you are not conscious of the machine, nor of your companions; the visuals become a compelling and immediate reality, however strange or artificial that reality may be.

INTERACTIVE MACHINES

From the very earliest days of the design of simulators for the leisure environment it was perceived that there was a requirement to make simulators interactive - that is there should be a "pilot" to control the experience. It was also understood that several simulators under individual human control should interact with each other. This is called "mutual interactivity".

Of course, if you have a large simulator with forty or more persons in the machine they cannot all be the pilot at the same time! The original idea was that one of the staff, suitably uniformed, would fly - or pretend to fly - the simulator through its pre-programmed sequence of about five minutes excitement.

In the "Tour of the Universe" experience in Toronto the illusion of a pilot is built into the experience by introducing visual shots of "Captain Moses" during the preliminaries to the intensive motion experience. The scenario also provides a continual background of the captain talking to the passengers throughout the flight and there is a pseudo intercom. discussion between the pilot and various controllers as part of the experience itself. A similar effect is produced in the Walt Disney "Star Tours" ride by using an animated "robot" in view of the occupants to the side of the screen and creating the impression that the flight is somehow under the control of this crazy little animated being.

You will understand, of course, that there is no real interactivity for a pre-programmed experience such as is presently employed in large simulator systems, which use film as the medium that carries the visual imagery.

In 1984 I made a proposal to the Corporation of Southend that four interactive simulators should be located at the end of Southend Pier under a development scheme then in consideration, so configured that any time two of these forty-seater machines were in operation whilst the remaining two were unloading and refilling. The simulators were intended to operate interactively under the control of "pilots" who would actually manoeuvre the vehicles (spacecraft in the proposed scenario) using visual imagery generated by a large Marconi computer that at that time cost £1.5m. The project turned out to be viable from a commercial point of view but we found that Southend Pier could not carry the forces that the simulators would generate and so the concept was abandoned.

The essence of true interactive simulation is the visual imagery, which must of course be computer-generated, so that the pilot has full freedom to manoeuvre the supposed vehicle in any direction at any reasonable speed. Unfortunately, good computer-generated imagery costs money. Seven years ago when the leisure-related simulation industry was just getting started we were talking about several million pounds for the computer system. Nevertheless, the idea that an exciting travel sequence could be created, if you like, "in the mind of a computer", limited only by the imagination of the programmers, was very attractive for the promoters of leisure simulation technology.

With the co-operation of the Marconi Company, the first Super X machine used CGI material (on video tape) generated by the Marconi "Tepigen" computer at Leicester, of a T45 Hawk operating from the USS Nimitz and having a shoot-up with an F15. The combat took place in a Welsh valley whose database was derived from satellite information and happened to be available to the Tepigen computer in an unclassified format. For the purposes of the exercise the Welsh valley was given a sea coast!

My original concept was that computer-generated imagery would permit a wide variety of unusual visual material to be generated, with the image generation computer also calculating the synchronised motion cues and recording these on videotape to provide a library of "experiences" for Super X machines. But by early 1986 it was clear that: -

1. The general public has no idea of the cost and computational difficulty of CGI and demands real-time graphics that have the same quality as the ray-tracing off-line graphics with which they are familiar from television advertisements and logos. The customers say that they prefer films of real experiences because of their better visual quality, even though these are less interesting than the fantasy experiences of CGI.

2. The motion that is applied to these simulators should not be mathematically correct but far more artistic. The public wants the artificial reality to be much more vigorous and exciting than reality itself: they want reality as they think it ought to be!

So far the public experience of simulation in the big Rediffusion machines and the Super X fourteen-seater machines, and in the Omnifilms, Showscan or Ridewerks motion cinemas, has been based on pre-recorded visual imagery pre-programmed with motion of the "hang on tight" variety.

THE PRESENT SITUATION

The general public - that is the people who pay money to experience "simulation" have been interested by the strange effects of accurate motion cues upon them; by the overpowering urge, triggered by precise motion cues, which forces the occupants of a professionally-Engineered simulator to watch the screen and to forget the outside reality. I think it may be helpful to describe some of the real simulators and some of the "semi-simulators" now on the market.

The Rediffusion machines, 40 and 60 seaters, are the largest and the best known simulators in the theme parks market. However, the general public will hardly ever see them because it is an important part of the "experience" that the simulator is never seen for what it really is. It is entered from a boarding tunnel similar to that used to dock with aircraft, ending a carefully-contrived psychological build up towards the boarding of the "spacecraft" or whichever vehicle is appropriate to the experience that is simulated.

These machines cost a million pounds or so each and consume more than a hundred kilowatts of electrical power. The 70mm. wide-screen films that are shown in them may only last a few minutes but they are very expensive works of art from the best in the Special Effects business. Large simulators are justified as profitable investments because they are much safer and more reliable than any other large motion-related amusement machine and because of the very strong psychological effects that the whole experience produces. **Everybody remembers their simulator ride!**

The Doron 12-seater machine, as I have already explained, was one of the first simulators and, because it is relatively light in weight and small in size, it can be located indoors in areas with a ceiling height of 12 feet or less. The machine was designed primarily as an amusement machine and not as a true simulator and because its bandwidth and power-to-weight ratio is small the appropriate motion effects that should correspond with the visual imagery cannot actually be generated. Nevertheless the general public is happy with what they get for their money and the machines are popular in more than 20 countries worldwide. John Barman's Astrojet machines represent a sort of "British Doron", being primarily designed as an amusement ride. They use a three-axis Flytsim motion base that was originally produced for my early Super X simulators in 1985 and 1986. Astrojet machines are now computer-driven and use visual material on U-matic videotape. Twenty Astrojets are operating in the EEC and Japan.

The Super X "Venturer" machine is now manufactured and marketed by the Leisure Products Division of Rediffusion Simulation Limited and is the most popular 14-seater simulator in the world today. It weighs 5.5 tonnes fully loaded and it uses a three-axis motion base and control system that has been developed to imitate to a large degree the sensations produced by a full six-axis machine. The Super X, Doron and Astrojet machines cost less than £100,000 and are usually operated on a "pay as you enter" basis; in a good location they can take £2,000 a day.

There are a number of cinema companies who sell a wide-screen display system, with special seats that are hydraulically powered and move in synchronism with the film display. The three principal companies in this business are Omni Films of Sarasota, Florida; Ridewerks of Burbank, California; and Intamin of Switzerland. The Intamin cinemas use Douglas Trumbull's "Showscan" film system.

The problem with moving-seat cinemas is that "true reality" is always visible; the screen does not move with the seats, as it would do if it were the front window of a vehicle. That is to say, there is always a stationary horizon or a constant vertical edge of the building which is in view or which comes into view from time to time, so that the brain is frequently reminded that the seat is **not** really moving with the visual imagery but is an artificial contrivance, merely creating interesting sensations.

Because the surface of the screen is not locked to the position of the seats, some common tricks of simulation cannot be used. For example, forward acceleration cannot be simulated by pitching the seat because the occupant will see an opposite change in the elevation of the screen horizon that depends on the location of the seat in the cinema. Similarly, sideways acceleration cannot be simulated by a seat roll, because the screen horizon provides a conflicting visual reference. The deficiencies of the motion simulation system in moving seat cinemas are offset by the exceptionally high quality visual experience, which is 70mm. high frame-rate, wide-screen, with a large vertical angle of view from a steeply-sloping auditorium. The presentation is supported by multi-channel sound systems of very high quality, providing excellent entertainment.

A common misunderstanding of the word "simulator" in the mind of the general public at the present time relates to the interactive videogame machines made by companies such as Sega, Taito, Namco and Atari. These are small arcade machines in which the punter plays a video game on a television screen whilst the seat moves under control of electric motors or hydraulic rams on a mechanism with a very low bandwidth and with limited power input. In most of these machines the surrounding scenery is always visible and the gamester can "show off" to his/her friends. There is only a limited potential for the motion to be linked to the visual system and, because the real horizon is always in view, there is no significant psychological disturbance and no "simulation" in the true sense.

Nevertheless, the games are popular because they provide an enhanced sensation of involvement, since the forces on the body are generated by the computer and are therefore out of the control of the participant. There is a continual sensation of struggle against the opposition of the computer that adds to the novelty of the game.

Recently, both Sega and Taito have introduced arcade game products which use a gimballed system capable of 360 degrees rotation on any axis and on several axes simultaneously, linked to a video game in the central housing into which the participants are firmly strapped. There is no lateral translation and the bandwidth is very low. Although I have not yet ridden one of these machines, I am told that the co-ordination between the visuals and the movement is not easy to understand and half the fun is the general confusion as to what is actually happening to you or how you are doing in the video game. Atari, in contrast, have introduced a game called "Hard Drivin" which does exclude the external environment to some degree and which is notable for the sophistication and accuracy of the modelling of vehicle dynamics and for the tactile feedback which is provided via the steering wheel. There is no motion system.

The machines provided for entertainment have previously been special-to-type; shaped to suit the idea that is being represented, such as a motorbike or a racing car, and changed every season. But Rediffusion have in development a twin-seater machine which was previously referred-to by its Super X project name of "Bandit". This is the first **general-purpose simulator** with accurate motion cues and 3D graphics to be sold into the arcade market. The concept of this product dates from 1986 and its design was crystallised by a series of discussions I had with a visionary American entrepreneur, named Allan Madsen, in 1987.

The machine is based on a three-axis hydraulic motion base of wide bandwidth, linked to a sophisticated graphics display, with the motion cues derived from a complex software model of the supposed "vehicle". (An aircraft, for example.) Not only is there a subtle and sensitive interaction between the pilot, the simulated environment and the mechanism of the simulator itself, but the machine has been designed from the start to be networked, so that several such "aircraft" or other vehicles can compete against one another in the same Virtual World. Although the product was intended for the arcade market, it is a thoroughly-professional machine, using technology that pushes to the limit what is achievable at an acceptable market price.

Finally we come to "Virtual Reality", of which the products of W. Industries, VPL, ARRL and Division are probably the best known. In 1989 I arranged for W. Industries to be financed by the Leading Leisure Organisation in order to provide the software resource for my Super X "Bandit" project. You will therefore find a significant similarity between the software that runs in the W. Industries games machines and the software running in a Bandit (although the Bandit software now comes from within the Rediffusion organisation). The W. Industries machine is entirely visual, there being no motion simulation, but it is commonly referred-to as a simulator because it includes many elements of the Sega, Atari etc. videogame genre. It also incorporates the concept of "vehicle", using joystick controls like the Bandit.

For those of you who are not familiar with the Virtual Reality concept, I will say that the most striking element is the head-mounted display system that creates a visual scene. The scene is a computer-generated Virtual World that is connected to the real world through the physical position and orientation of the head of the person wearing the goggles. As the head of the user turns or tilts, sensors inform the computer of the new head position and the visual field is updated as though the person wearing the head set is immersed in a Virtual World surrounding him/her on all sides. This is a very interesting effect, to which I will return later.

TECHNICAL ASPECTS OF INTERACTIVE MACHINES.

I would like to review the Engineering problems relating to the developments in simulation technology that I have just described.

MOTION BASES are either "Stacked" or "Synergistic".

In **Stacked** systems each axis of motion has its own actuator - one actuator produces a heave motion (up and down) for example, a second actuator produces the roll motion and so on. Clearly, the motion-producing mechanisms have to be built one upon another; hence the “stacked” name. An example of this can be seen in the Showscan/Intamin cinema seat mechanism. **Synergistic** mechanisms, on the other hand, require more than one actuator to operate for each axis of motion and therefore each actuator is shared between several axes. Since motions in several axes occur simultaneously, the design makes great demands on the physical limitations of each actuator. Nevertheless, a rigorous analysis will show that a synergistic mechanism is lighter, simpler and more reliable than a stacked mechanism, although the controlling software is somewhat more complicated.

An object may be manoeuvred in space with any combination of six motion axes - three rotational axes and three linear axes. If we think of the set of Cartesian co-ordinates and imagine ourselves to be travelling along the X axis, the rotational axes are **Roll;** (rotation about the X axis), **Pitch**; (rotation about the Z axis) and **Yaw**; (rotation about the Y axis). The translational motions are **Surge**; (motion along the X axis), **Sway;** (motion along the Z axis) and **Heave**; (motion along the Y axis). It will be appreciated, of course, that when the vehicle is in motion the Y axis is not always aligned with the gravitational vector and the X axis is not always coincident with the motion vector. The convention is that the axes of motion are viewed from within the vehicle and are not related to any absolute co-ordinates.

Of course, the simulator motion base itself is normally fixed in relation to absolute co-ordinates. This gives the simulation engineer the ability to fool the occupants of the capsule by interchanging inertial and gravitational forces, using pitch to produce a sensation of surge, roll to suggest sway and a combination of both to imitate the centrifugal force dependent on the rate of yaw. The most sophisticated motion systems use the well-established six-axis synergistic design that makes a flight simulator instantly recognisable. This mechanism is expensive and for several reasons it is difficult to scale down for use in small simulation mechanisms.

All of the smaller machines therefore use a three-axis mechanism, providing a facility for simultaneous heave, pitch and roll. To an extraordinary degree, it is possible for a three-axis motion system to behave convincingly as a full six-axis mechanism. As I have just mentioned, **Surge** acceleration can be simulated by coupling to the gravitational acceleration vector, simply tilting the machine backwards or forwards as required. **Sway** acceleration can also be simulated by using the gravitational vector, rolling the capsule as required. **Yaw** is not a significant acceleration in itself but it is felt as a centrifugal force whose vector moves in a way that depends upon the event that generates the yaw acceleration. This can be simulated by gravitational coupling once again, tilting the capsule downwards in the direction of the perceived centrifugal force vector in proportion to the **Yaw Rate** of the vehicle model.

Clearly, because it takes a fraction of a second for a three-axis mechanism to move the capsule in rotation so as to produce the pseudo-surge, pseudo-sway and pseudo-yaw, the "edges" of the motion are not accurately represented. This inaccuracy is generally lost in the excitement of the visual imagery, the sound background and the "feel" of the controls.

THE VIDEO PRESENTATION in an interactive simulation experience does not have to be of ray-tracing standard with crisp shiny edges, fine detail and subtle coloration. The enjoyment of an interactive experience is not centred on an appreciation of the scenery but in the convincing representation of movements, distances and the perception of a three-dimensional environment. For a satisfactory and absorbing experience, we have found that a few hundred polygons properly lit and textured are quite adequate, providing that attention is given to the increase of detail at short ranges and low relative speeds.

In an interactive motion simulator one of the most crucial parameters is that of frame update rate. It is no good having a beautiful picture that jerks along at ten frames per second; it is much better to have a simpler picture flowing smoothly at thirty frames per second. (Of course, as computing power increases we can do both, but when compromise has to be made, **frame update rate is more important than picture detail**).

The choice of visual angle (angular width of the field of view) is a difficult one. The sense of motion is lost if the visual angle is narrow vertically or horizontally; but every increase in the visual angle also increases the demand on computing power by the requirement for more detail. The compromises that we have to make now will be eased as the cost of computing power continues to decrease and we are able to "zoom in" to a closer feeling of involvement with the screen visual imagery. In an earlier section of this discourse I mentioned the powerful effect of wide-angle visual displays in motion cinemas and it is certainly our objective to move towards wrap-around horizontal and vertical edges to the visual displays of simulators.

At this point I ought to mention the very interesting effects that are produced by collimated displays - that is, displays that, by means of mirrors or lenticular screens deceive the eye into believing that the image is thirty feet or more away from the eye of the participant. The first effect is to remove the perception of the image as being a television image, because everyone knows that television images are just not seen from thirty feet away and the brain refuses to accept it, rejecting the idea that there are scan lines in the picture. There is also the strange effect of the visual image appearing to be viewed through a window, so that it is actually possible, by leaning forward a bit, "to see out more to the sides of the window" or to the top and bottom as appropriate.

There has been some discussion as to the appropriateness of stereoscopy in interactive simulators, particularly now that the Virtual Reality goggles have come to the knowledge of the public. In fact, stereoscopy is only important for objects that are relatively stationary and relatively close. Neither is common in an interactive motion simulator. When the head moves and the body travels the brain builds up its concept of size and distance from a series of views as the participant moves towards or past the object in question. The brain learns to construct a three-dimensional understanding of the image from the series of differences in the same way that radar or ultrasound systems construct three-dimensional views by the "synthetic aperture" method. In training simulators it is often necessary to generate images of the "virtual controls of the vehicle". In these circumstances it is very effective to have these stereoscopically adjusted to be much nearer than the scene "out of the window".

There is another interesting aspect of stereoscopy that might be worth the use of another computing channel to produce it. Stereoscopy reduces perceived noise in the picture because the noise is seen differently in each eye and can therefore be recognised as a visual defect. The brain carries out a noise-cancelling adjustment that has a remarkable effect of cleaning up the picture. This effect of stereoscopic noise-cancellation also helps to remove the perception of television scanning lines and improves the perceived clarity of moving objects.

Finally, in relation to visual imagery I might emphasise that it is very important to isolate the external environment and to isolate from the field of view all distractions that relate to real internal construction of the simulator itself and which do not suggest the perceived vehicle that is being simulated. This means that the inside of the simulator must be a dull matt black and that all shiny surfaces need to be taken out of the field of view of the occupant. It is not dark inside a simulator - the light from the screen illuminates the interior of the capsule.

COMPUTER-GENERATED SOUND is becoming a very sophisticated business, with the objective of increasing the sensation of "ambience" and even the perception of distance and speed from appropriately generated sound cues. This means that money has to be spent, not just on the computing power but also on the sound amplifiers and loudspeaker systems that have to operate in the confined space of an interactive simulator.

THE ERGONOMICS OF SIMULATOR MACHINES merit some comments here. It is important that the participant feels comfortable - in fact he should lose all consciousness of his actual whereabouts and be convinced that he is fully immersed in the imagined reality of the simulation. This means that the controls have to be carefully designed to blend into the consciousness of the human being, in the same way that a properly designed automobile steering and pedal system quickly becomes an automatic extension of the human body.

For health and safety reasons, it is difficult to arrange for a simulator which is designed for general use by the public in an amusement arcade or simulation-centre environment to be fitted with control systems which are adjustable to the human body. That is, steering wheels and control pedals are not easy to design so that they can be used by a fully-grown adult and then, moments later, just as effectively by a youngster. There are problems of health and safety "obstruction to emergency escape" and of course there are problems of vandalism. It therefore seems likely that for the foreseeable future the controls of a general-purpose interactive simulator are likely to be a couple of stubby joy sticks tucked out of the way of escape, but just as accessible to young children as to adults. There are similar problems relating to the capsule entry and exit arrangements and to the movement of the hood or door that obscures the external environment and encloses the occupant. The door has to be moved easily and safely by a small child, but it must be strong enough to prevent it being destroyed by the vigorous actions of a hasty adult.

DESIGN PRIORITIES.

The two most important design criteria for entertainment simulators are: -

1) **They have to be very reliable.**

Simulators are intended to be in use for at least twelve hours a day almost continuously and probably for up to twenty hours a day in some overseas installations. They are going to take a hammering from the simulation motion system and they are going to take a hammering from the constant stopping and starting, entry and exit of many excited users. It follows of course that they are being most profitably employed during these times and the consequences of a breakdown then will be very expensive. The design process must be **targeted towards ruthless simplicity** and towards toughness, resilience and survivability. Money spent on achieving these objectives is easily justified against the costs of warranty and maintenance.

2) **They have to be low-cost.**

It is easy to design a simulator which is a beautiful piece of Engineering, with great subtlety and sophistication and which, as a working prototype, demonstrates clearly the technical abilities of the Project Engineer. Unfortunately, that is not what the customer wants. The customer just wants to make money!

In 1986, I was operating a simulator in an amusement park, close to a conventional fairground machine operated by Billy Chipperfield of the famous Chipperfield Circus family. He watched me for several days and then, leaning over the fence, said helpfully that I should realise that he and his family, and their friends to whom I expected to sell some of these machines, did not actually mind the high technology providing that the machine was low-priced and very reliable! He had seen my pride in the machine and wanted me to understand that, what to me as an Engineer was an achievement in the use of technology to improve the quality of entertainment, was to him “acceptable” only if it made money. After all, Money is what our customers pay in order that we may be paid our salaries: Money is what Engineering is actually about.

We can be encouraged by the rapid rate of increase in value of simulation in the leisure industry. My first simulator in Brighton in 1985 sold for £70,000 and the operator charged 50p for a three-minute ride. A year later this was 80p and then £1 and now £2.50 for a really good simulation experience is thought to be quite acceptable. Engineering development in several areas has increased the value of the leisure simulator faster than its cost and it has provided a good income for very many people.

MARKET SIZES.

A product is only worth developing if there is a market which justifies the cost of the development by profitable sales. The market for personal simulators is very large indeed.

The "Market Universe" is the number that results if you add up all the potential sites into which a particular product could be placed in the world in the foreseeable future. Of course, only a fraction of this universe will actually make a purchase, and the sales will proceed over a period of time, so that, generally speaking, the annual sales for a product will be in the order of a few percent of the size of the market universe.

I have been surprised at the wide range of profitable uses that have been found, even for passive simulators. For example they are used: -

1. **To draw a crowd to a particular area - as an attraction.** They can be used at exhibitions and they can be used to bring "life" to any quiet area.
2. **To extract money from a crowd which has gathered** for another purpose. They can be used in the waiting areas of airports, on railway stations, on showgrounds, in shopping malls, etc.
3. **For amusement purposes.** They are an ideal extra choice in fairs and amusement parks where their unique attraction appeals to all the family.
4. **For advertising.** The machine itself is an attraction that can be decorated with advertising and the captive audience within the machine is receptive to advertising on the video screen.
5. **For education purposes.** They can be used in museums and exhibitions to illustrate clearly and in an interesting way aspects of travel, animal behaviour, the local environment and so on.

The important thing to note is that simulators are attractive to people of all ages and that all ages can ride the machines simultaneously. **This makes simulators different from any other entertainment device**.

Simulators are used in a large number of locations, such as: -

1. **Piers and fun fairs.** 2.**Theme parks.** 3. **Museums**.

4. **Stately homes and safari parks.** 5. **Amusement parks.** 6. **Caravan parks and camping sites.**

7. **Exhibitions and promotions.** 8.**Hotels and holiday centres.** 9. **Zoos and aquaria.**

10. **Shopping malls.** 11. **Leisure facilities and sports centres** 12. **Mobile machines.**

13. **Airports, railway and coach stations.** 14. **Ferry terminals.** 15. **Motorway service areas.**

16. **City centre attractions.**

When I first produced the Project Plan for the design and development of the Super X range of fourteen-seater simulators, I had a limited view of their potential application. Nevertheless I calculated that the market universe for these machines exceeded 6,000 units. That estimate has now risen to **10,000 units.**

Small interactive machines will sell into all the locations open to the larger passive machines and what is more they will sell in fours and fives where only one passive machine would have been located otherwise. In addition, groups of simulators may be sold into themed "simulation centres" as a totally new form of entertainment attraction. For these reasons and because small interactive machines begin to enter the top end of the amusement machine market, the perceived universe for sales of small interactive simulators is in the order of **100,000 units.**

Finally, we might consider the size of the market for a personal simulator, designed to be used in the home. This market is certainly one hundred times greater than that of the smaller interactive machines, so that we are talking about a market universe of more **than 10 million units.**

Products wear out and become obsolete, so that after a few years when a new product has spread into the market it begins to generate a sort of "dynamic demand" in addition to the original demand for first sales. The car industry, for example, runs very largely on this dynamic demand.

Software is the essence of simulation. Because the entertainment industry creates a continuous demand for new Experiences, the market for software sales quickly becomes a simple multiple of the installed total of simulators at any time. It can even be argued that the really profitable business is the software business and the simulators themselves ought to be sold at very low margins in order to create it.

VIRTUAL REALITY.

1991 has seen an explosion of interest in Virtual Reality, largely triggered by the interest of the media in this emerging technology. This year W. Industries entered the arcade system market with the first complete "Virtual Reality rig", well presented and well promoted. As I think most of you will agree, there is a big difference between Virtual Reality as conceived in the minds of the media and projected to the general public as "here and now technical achievement" and that which actually exists and can be experienced today in an amusement arcade or at a technical exhibition. Today, Virtual Reality is an illusion. Virtual Reality is only a virtual reality. To quote Robert Stone of the UK Advanced Robotics Research Centre, "With today's levels of technology it is also a form of sensory deprivation ... despite claims to the contrary, it is glaringly obvious to most human factors or ergonomic practitioners that the VR equipment we now see gradually creeping into the lives of ordinary people is not yet ready to do so". To quote William Bricken of the University of Washington, "Virtual Reality is in the unique position of being commercially available before it is academically understood".

It is interesting, it is exciting and it has a huge long term potential as a **personal** (not an amusement arcade) product. (The idea of sharing items of clothing with a thousand different people each week is definitely not attractive!) But however beautifully-shaped and carefully-coloured the visible bits are, the subsystems which must make it all work are at an elementary design stage and probably ought to have remained in the back room for another year or so. But now the cat is out of the bag and the public wants all it can get; I think that W. Industries will actually be quite successful!

It is useful to examine the essential elements of "Virtual Reality" and to analyse the areas in which significant engineering investment still needs to be made: -

The essence of the concept is that a display system which moves with the head shall have fed to it computer-generated imagery which represents an artificial environment just as it would be seen from the instantaneous position of the user's head. A display screen for each eye individually allows virtual objects that would be close to the viewer to be represented with good stereoscopic effect.

The second key aspect of "Virtual Reality" is that it is body-related and not vehicle-related (although it can be both). One of the central concepts is that the artificial environment displayed by the computer to the wearer of the head-set can be influenced by the actions of the wearer's body; limited, at the present time, to the actions of one hand wearing a "data glove".

For the Virtual Reality concept to be realised to an acceptable and useful degree, we have to solve the following problems: -

1. **THE HELMET** must be reduced in weight and the display unit greatly reduced in size and/or moved away from the front area of vision. Present designs are psychologically oppressive.
2. **THE IMAGE GENERATION** is extremely crude and because the experience depends entirely upon that visual imagery, its present defects are quite unacceptable. The frame update rate in particular is much

too slow - a series of studies have shown that to sustain a credible model of a virtual environment during a natural rotation of the head, the frame update rate has to be about 200Hz.

3. **THE HUMAN HEAD POSITION SENSOR** has to be reduced in cost, increased in range and speed (to match the higher update rates) and made fully-tolerant of anomalies such as steelwork in the surrounding real environment.
4. **THE ANGLE OF VISION** in the headset has to be substantially increased. If you think about it, your sensation of the environment and your position relative to objects in that environment depends strongly on peripheral vision, horizontally and vertically. Each eye needs to see a real solid arc of more than 60°, with a central stereoscopic overlap region. **This is not the same as looking through a small eyepiece, which subtends an angle of only 30°, at a display that is expanded to, say, 100°. It must be possible to gain a sensation of presence in the environment by normal scanning movements of the eyeballs.**
5. **THE OPTICAL RESOLUTION** needs to be increased by a large factor. Existing systems have a resolution of about 300 x 300 for 100°, or 20 arc minutes/pixel whereas a resolution better than 2 arc minutes/pixel is required for each eye in order to achieve the proper clarity and accuracy of perception in the central field.
6. **PHYSICAL MOTION SENSATION** is required to give a proper degree of personal involvement in an environment, even when the movements themselves are small.
7. **NAUSEA** The feeling of sickness that sometime occurs in simulators is caused by a mismatch between the timings of visual and motion cues. In a vehicle-related simulator both the visuals and motion are under the control of the system computer and a very tight synchronism can be maintained. Unfortunately this is not true of a Virtual Reality helmet system and nausea is common. The trouble is due to the finite time that it takes for the head sensor to recognise a new head position, following which the computer must recalculate the visual scene and update the television frame.

   Recent work has shown that any delay greater than 5 milliseconds is likely to have a subconsciously disturbing effect. Present systems have delays in the order of 100 milliseconds and there is no immediate prospect of a low-cost solution to the problem.

In due course, all of these technical objectives will be achieved and we shall have expanded the concept of a computer interface to the human body so that we have something like a "flying suit" from which sensors derive information on the movement of the wearer, and into which artificial sensations of touch, force and movement are impressed by computer-driven actuators. There are all sorts of interesting possibilities to this concept including the communication to disabled people of the sensations of physical activity of which they are not capable, and the communication to a normal human being of the sensations of superhuman abilities (enormous strength, ability to fly etc.). The experience of good "Virtual Reality" is a highly intellectual one with many dream-like connotations and I will return to some discussion of this at the end of the lecture.

It is useful to distinguish between videogames, vehicle-related simulators, and virtual reality helmets: -

In an arcade videogame which suggests that an aircraft is being flown, for example, the aircraft itself appears on the video screen and the player "flies along behind it". Similarly for a car, a helicopter, or anything else, the player is distanced from the action, so that even if a catastrophe occurs it can be viewed quite dispassionately. In a vehicle-based simulator, the visual display represents the front window of the vehicle, bringing the occupant into closer involvement with the artificial world so that the emotional link with the action is enhanced; what happens to the vehicle is felt by the occupant. Virtual Reality visual displays immerse the user directly into the artificial world, **which is inescapably in view in all directions,** providing a very strong emotional connection and a distinct feeling of vulnerability.

SOFTWARE.

Designers of systems have to remember that **"The system is the software".**

The hardware should be seen as an instrument that is played by the software, as a tool by which the software achieves its end objectives. However interesting the hardware may be in itself, it does not do anything unless it has software operating within it. If the software is good then the equipment is good, and vice versa.

So far in this lecture I have concentrated mainly on the hardware, but it is really the software that sells simulation equipment. I am sure that you will have considered the situation that might exist today, for example, if all the virtual reality hardware we need were already available off the shelf and of the highest quality. "Virtual Reality" would still be an illusion because we would not have an established source of the software. The same is true of personal simulators. The hardware cannot be marketed without an ongoing supply of software. After he has no more use for the first "Experience", what would the owner of the hardware do next? How about compatibility of software between different makes of hardware? How about improvements, enhancements and updates? Would the software cost more than the hardware? Should the hardware be provided almost free in order to create a market for the software?

I think we have some indication of what is going to happen by looking at past experience. In the early days of film-making, the film makers **may** have had in mind the vague concept of cinema chains, distribution networks, film studios, different projection systems, and so on, but these all had to come into existence step by step and in parallel to create the industry that exists today. Cinemas are useless without films, but nobody is going to invest in a first-rate film studio until there is a large network of cinemas. A similar thing has happened with the microcomputer industry; as soon as it grew to any size the software support industry began to dominate and even to exert a large measure of control on hardware manufacturers like the mighty IBM. The strategy of IBM for the development and sales of microcomputers is now dependent upon deals with software manufacturers such as Microsoft.

The serious training simulator industry, now that it is moving into the entertainment business, is being forced to re-examine its software organisation. Simulation hardware manufacturing companies, Engineering companies, now have software staff who are disciplined to create small numbers of very accurate models of complex vehicles and their operating environments for use in training simulators. For the entertainment market they must instead create highly imaginative fantasy scenarios and do so at frequent intervals, selling the copies of software in large quantities. Interactive entertainment simulators will not sell without an existing basic resource and an ongoing supply of software. The software houses which are needed by the simulator manufacturing companies have to be much more artistic than scientific, because what is most needed is an imagination which treats the hardware, the simulator, as a new tool to express an imaginative and entertaining idea.

That is not to say that the simulation industry can accept software of an undisciplined quality. Video games merely have to work, because they do not usually have an interface with anything except the video screen and the controls. They do not need to be subjected to the disciplines of documentation and standardisation that are essential in the Engineering industry itself. However, professional simulation, even for the entertainment industry, does require this discipline because a rapidly-evolving hardware capability needs a software resource which is standardised in many areas, such as in the construction of the vehicle models, the networking interfaces, the interfaces between visual systems, motion systems and control equipment, and in the compliance of the system with Health and Safety regulations such as ICSE "SafeIT". There is, at the time of preparing this lecture, no independent software resource that is capable of supporting the personal simulator industry that is about to emerge. When the simulator software industry is up and running, it will exert its own pressure for the rapid development of personal simulation hardware.

FUTURE DEVELOPMENTS

Keen observers of the simulation industry and its development towards the consumer market will see, during the next few years, a series of key developments which I will summarise as follows: -

1. **VIDEO**.
Very powerful low cost image-generation hardware is under development by several companies, with the objective of moving into the market for low-cost three-dimensional real-time displays, with increasing degrees of sophistication in texturing, lighting and surface reflectivity. We have to achieve image-generating power equivalent to several hundred MIPS for less than £1,000 and preferably on a single card. I do not think it will take us very long.

2. **DISPLAYS**.
We have to improve the screen picture quality up to at least HDTV standard with a frame rate of at least 30Hz. For display goggle systems we have to achieve at least 100Hz and 120 degrees solid angle. I think this is a few years away yet; in the meantime we will have to accept a lower quality product.

3. **MOTION SYSTEMS**.
There are very encouraging developments towards the achievement of low cost, silent, high reliability, safe and efficient motion systems. Watch this space.

4. **HUMAN INTERFACES**.
You will see developments that allow the direct sensing of the actions of a human body by a computer system. Other developments will permit the direct impression on the human body of responses by the simulation computer to events in the virtual environment that surrounds the simulated experience. You will see some interesting developments in the design of simulator control systems and in the total concept of a personal simulator system.

5. **SOFTWARE**.
The low cost simulation industry, driving towards the objective of selling simulation to the general public for use in a living-room environment, is beginning to grab the attention of the software industry. As the powerful and impressive hardware tools become available, you will find that a number of software houses dedicate a significant section of their workforce to the support of the highly profitable industry that is about to emerge.

6. **COST**.
I believe that you will see professional simulation equipment enter the home environment when the retail price falls below the equivalent of about £5,000 in the United States and Japan and below about £3,000 in this country. I expect the market to open up completely when the price of a complete system comes within sight of £1,000 - and earlier if a sort of "Simulator Rentals" company gets into the business.

DOMESTIC SIMULATION EQUIPMENT

Clearly, a personal simulator cannot look anything like the amusement arcade or simulation-centre machines that already exist. Such equipment quite literally weighs a ton, operates from a three-phase mains power socket and is often filled with hydraulic fluid. A domestic simulator has to be lightweight, consume only a few hundred watts of power, be silent, reliable and, above all, be completely safe. Whilst it has to be designed to stand up to vigorous operation by big Joe, it has to be safe in the hands of little Jane, who is likely to use it when the baby is crawling around nearby. Such a demanding specification poses difficult problems, but I think you will be pleasantly surprised at the technology that is coming together for their solution.

Networking for several simulators in the same home and networking between several homes simultaneously via modem links is not only feasible but I believe it to be **an essential feature** of the design specification. An important part of the attraction of simulation to the general public is the very interesting idea that they may interact with each other in the virtual environment of the simulation database.

As I have already said, the market for personal simulators cannot exist unless there is a good foundation of software to drive them, with an assured supply of new "Experiences" for the future. The simulation software industry will probably distribute its products through the existing chains of computer stores (for outright sales) and Video shops (for short term hire).

A REASON FOR CONCERN?

What we are about to do is to create a new industry which will employ large numbers of people across the world in the design and manufacture of the hardware and software for personal simulation equipment. We are going to generate products for sale in computer shops and department stores and we are going to create a need for an "Experiences section" in video shops. We are going to find another way to keep the kids quiet for hours at a time, and they will even be able to "visit" their friends without leaving the house.

So why should we be concerned?

Well, **the essence of simulation is that it is a compelling fantasy.** If you have never ridden a good simulator then I can only assure you that you will be very surprised just how compelling it is. Thorough simulation is capable of disconnecting you thoroughly from the real world and immersing your mind within a Virtual World, in which you are not limited to being the self that you are in your existence outside the simulator.

As I have previously explained, many of the effects on you are induced subconsciously; they go directly to the part of your brain over which you have no direct control and even if you are intellectually aware of how the simulator is designed and how it is achieving these disturbing effects, it is very difficult to stand back and observe yourself objectively in such a situation. The temptation is to concentrate on all the action in this virtual environment and get on with the interesting and exciting job of flying or driving the simulated vehicle and participating in the competitive event which is taking place, between you and the machine or between you and your friends in other "vehicles" in this Virtual Environment. You will find that the stress which is placed on you by your natural urge to compete and even to "survive" in such an environment does not make you want to get out of the simulation but actually to go further in. This effect has been observed for many years in professional training simulators.

Now if well-trained and disciplined people with a high intellectual ability find these simulators impressive, what is going to be their effect on highly-stressed or neurotic people, on persons of lower intellect, or on younger, less experienced and less educated people? I am personally convinced that many of these individuals will be overwhelmed by the power of the experience and they will be deeply affected by their exposure to it.

I think we will have problems with addiction, much greater than the addiction problems of conventional video games. Worse still, I think that some people will begin to believe that the abilities which they possess when they are immersed in their Virtual World within the simulator are their **real** abilities, which they will try to carry with them into their everyday environment. In the simulator they are immortal, they may have superhuman strength and they may be capable of flying, of moving through walls and of breaking glass without being cut. Clearly, it will be very dangerous for someone to try to live in the real world with such unrealistic convictions about their abilities.

There has already been some serious discussion as to whether even the crude "Virtual Reality" which is available today is or is not a drug-like experience. Certainly, I believe that the creative fantasies of some of our best software designers, expressed through the medium of a professionally-engineered simulator, will be capable of impressing upon the human psyche sensations and memories which are capable of changing a person's perception of the universe.

Normally our fantasies, good and bad, are worked out in our mind when we are dreaming, either in a normal sleeping condition or when we are in a deeply contemplative and passive state in our chosen environment. Our brains are able to discriminate clearly between reality and the products of our imagination. However, I suspect that we are now going to inject into our brains ideas that are firmly connected with bodily sensations and with the flow of hormones in active response, during a time when we know that we are **not** dreaming and we are **not** in deep contemplation.

I am concerned that it will not always be possible for the brain to put simulation fantasies into the "fantasies" file and realities into the "realities" section, and I think we ought to keep an eye open for complications that may arise. Really good simulation is a sort of "brain washing" and it may have effects that are not always beneficial.

CONCLUSIONS

If I may summarise; during the last six years or so we have begun to generate a large demand for personal simulation, but we need to invest in the development of: -

COMPUTING POWER FOR IMAGE GENERATION

MOTION SIMULATION SYSTEMS

VISUAL DISPLAYS

SOFTWARE.

It is my view that a very large market for personal simulators will open up when these developments achieve critical cost objectives within the next few years.