Royal Aeronautical Society Hamburg Branch

DGLR, VDI, HAW Hamburg

29th January 2009

Development of Aircraft Simulation – An Essential Part of Training and Aircraft Design

Hugh Dibley, MILT, FRIN, FRAeS
Airbus A320, A330, A340 Pilot Instructor
Ex Technical Pilot, Airbus Training, Toulouse
Member RAeS Flight Simulation Group Committee

Ex BOAC / BA B707, B747, TriStar - Instructor & C/A Test Pilot
As Pilot Navigator: Douglas DC7C, Britannia, Comet 4

History
- of aviation

Need for Training

Development of Simulators

Simulators for Training

Vital part of airline finance

RAeS Flight Simul'tn Group

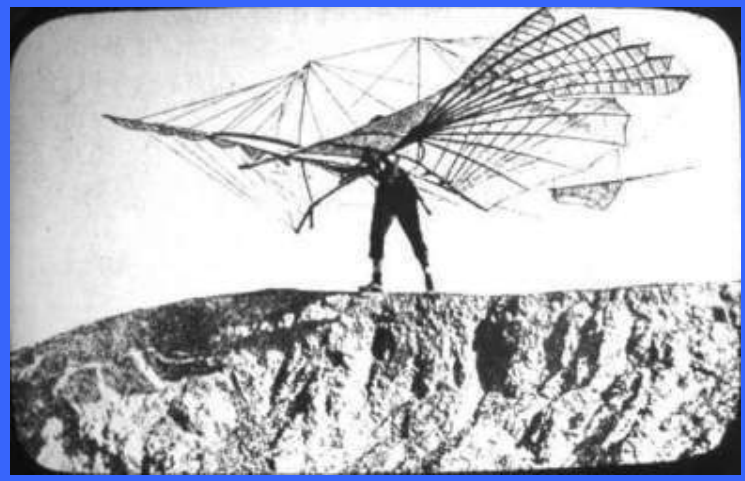
Engineering Simulators

Space Tourism Simulation

Military Simulation

History – of Aviation and Simulation

1452-1519 Leonardo da Vinci - amazing concepts

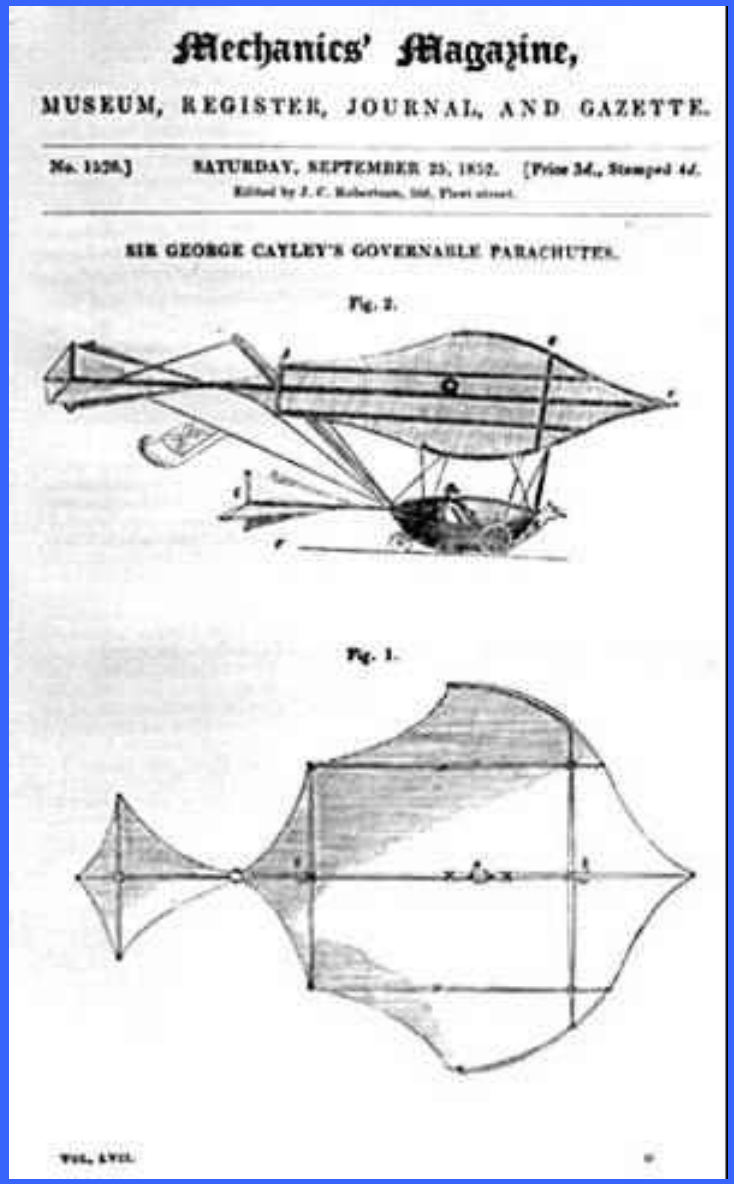


1848-96 Otto Lilienthal - theory and practice

The Cayley Medallion, depicting (left) a Monoplane Glider and (right) Lift and Drag - 1799

1773-1857 Sir George Cayley – developed theories of aircraft control, built first manned glider

History – of Aviation and Simulation



Mechanics' Magazine,

MUSEUM, REGISTER, JOURNAL, AND GAZETTE.

No. 1528.] SATURDAY, SEPTEMBER 25, 1852. [Price 3d., Stamped 4d.

SIR GEORGE CAYLEY'S GOVERNABLE PARACHUTES.

Fig. 2.

Fig. 1.

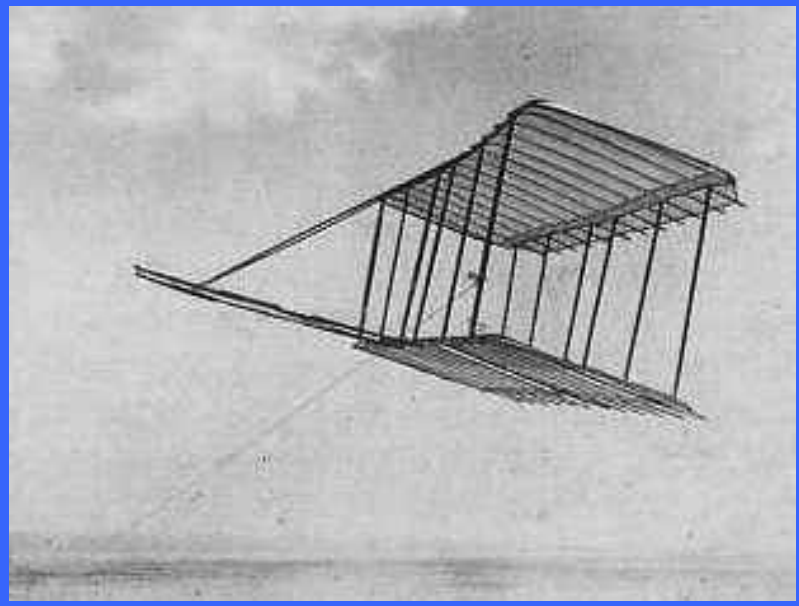
VOL. LVII.

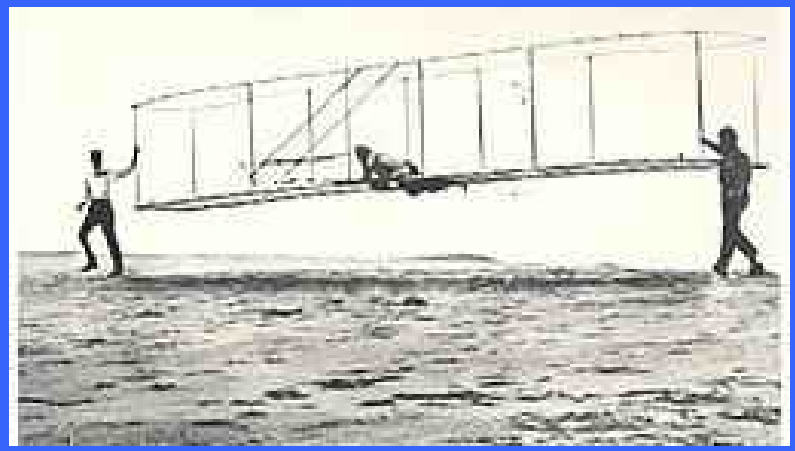
Sir George Cayley's Governable Parachute 1852

Replicas of the Governable Parachute 2003

History – of Aviation and Simulation

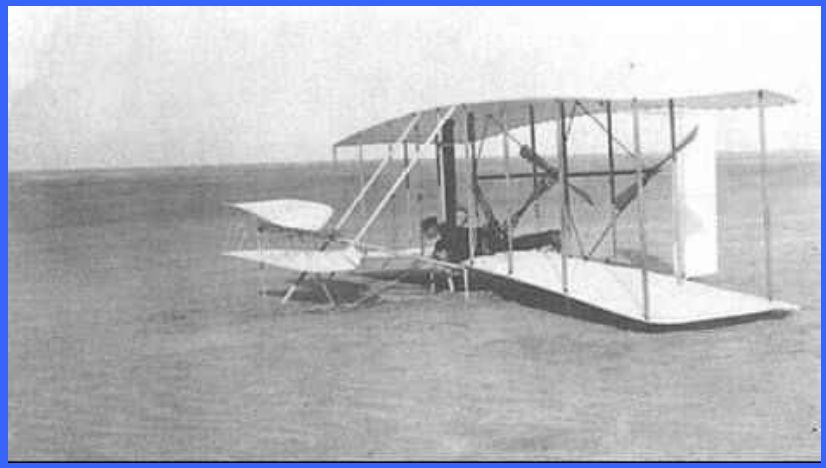
Orville and Wilbur Wright
Learnt from theories of Cayley & Lilienthal
(Published by the RAeS formed in 1866)



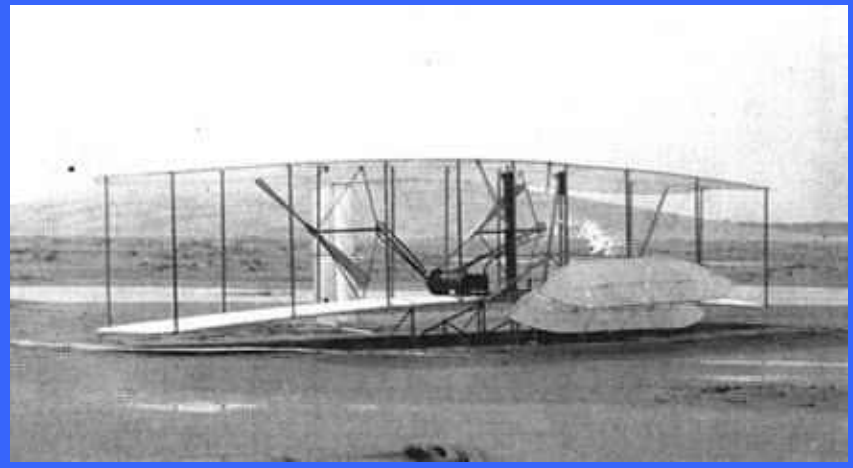


Developed controls through wind tunnels & tethered gliders.
Improved aircraft control & their flying skills in gliders.
All a form of simulation?

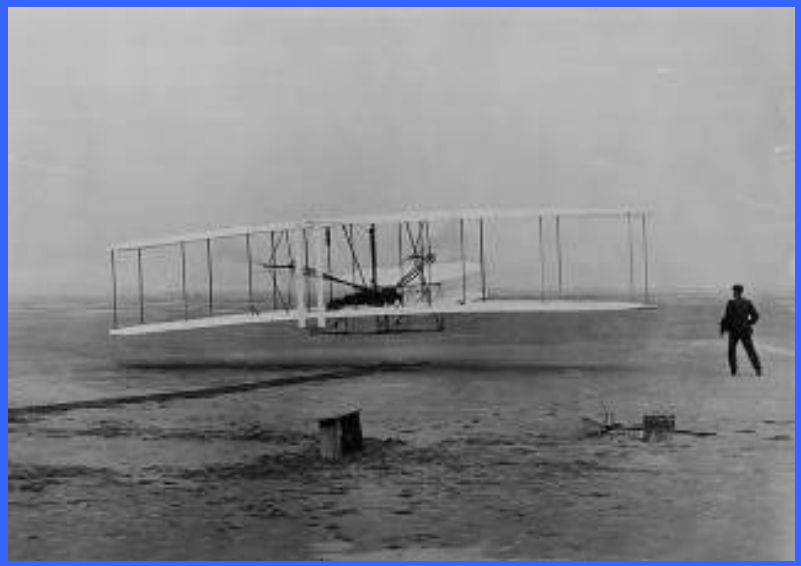
History – of Aviation and Simulation



Canard at front of Wright Flier was for control & safety



Wright Flier crashed during later flight



Historic First Flight 17 December 2003

Travis Long/AP

A replica of the 1903 Wright Flyer crashes during takeoff at Kill Devil Hills, N.C., on Tuesday The pilot was not injured.

Flyer replica crashes in trial

100 years later, some replicas were even less successful

Indicates a need for some form of Flight Training!

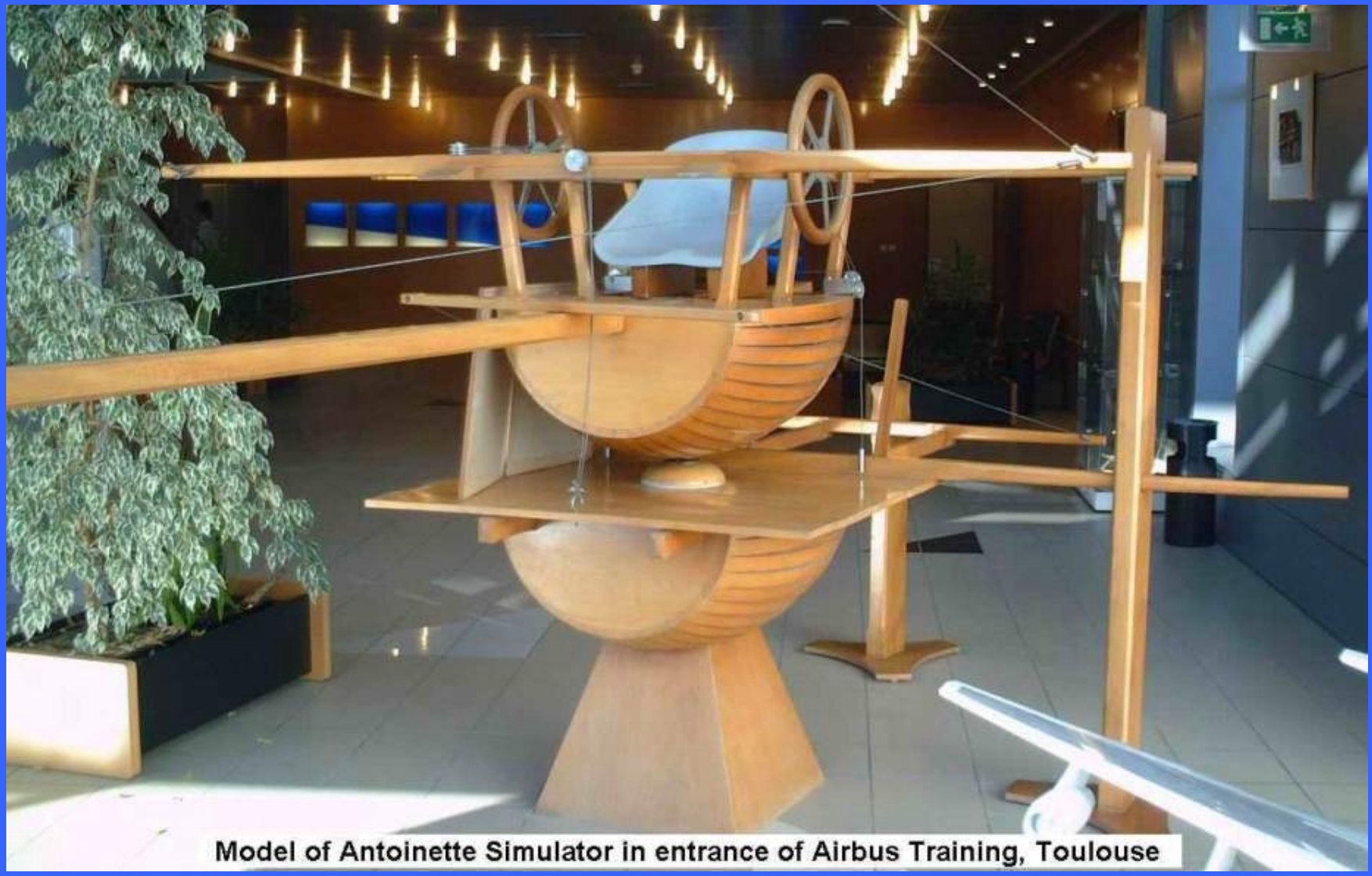
History – of Aviation and Simulation

Early Flight Simulator developed for training in aircraft handling

Photo of 1909 Antoinette Flight Trainer

Photo of Antoinette Aircraft in Airbus Training, Toulouse

History – of Aviation and Simulation



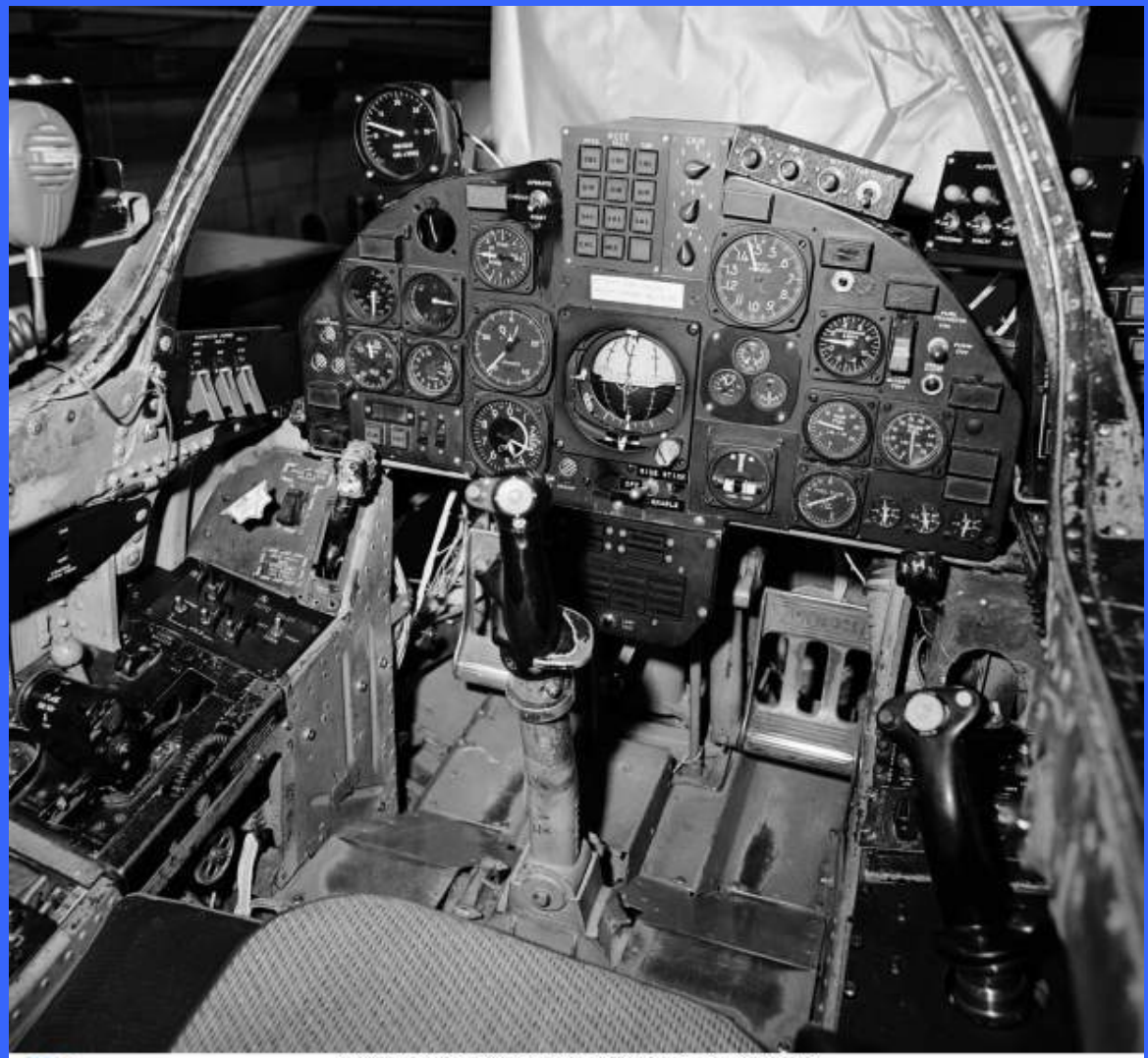
Model of Antoinette Simulator in entrance of Airbus Training, Toulouse

Flight Simulators for Crew training in Research Aircraft

Aircraft as Flying Test Beds – F8 for Shuttle Control Laws

Dryden Flight Research Center EC77-6988 Photographed 1977
F-8 DFBW (Digital Fly-by-Wire) contributed vastly to systems
aboard the Space Shuttle. NASA Photo

Aircraft as Flying Test Beds – F8 for Shuttle Control Laws



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: E-28613 Date: 1975 Photo by: NASA

F-8 Iron Bird Cockpit

Shuttle Simulator for Crew Training

Led to Successful Shuttle Operation

Aircraft – Used as Simulators

- NASA B-737 Flying Laboratory – Langley 1980s

Development of Flight Simulators

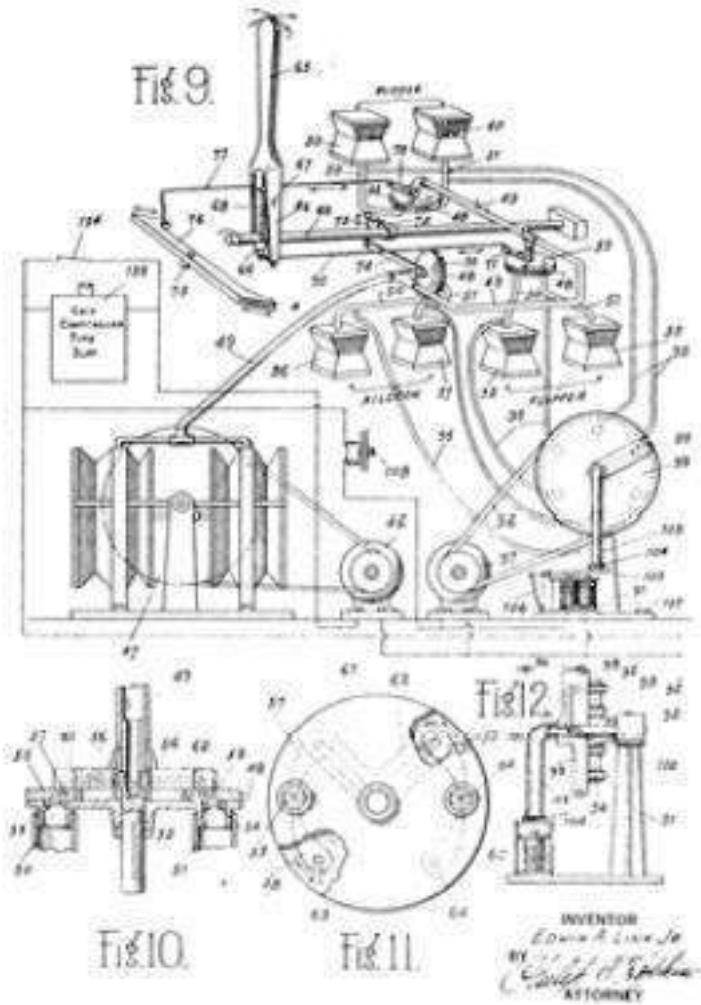


Fig. 6 Illustration from patent 1929/1931

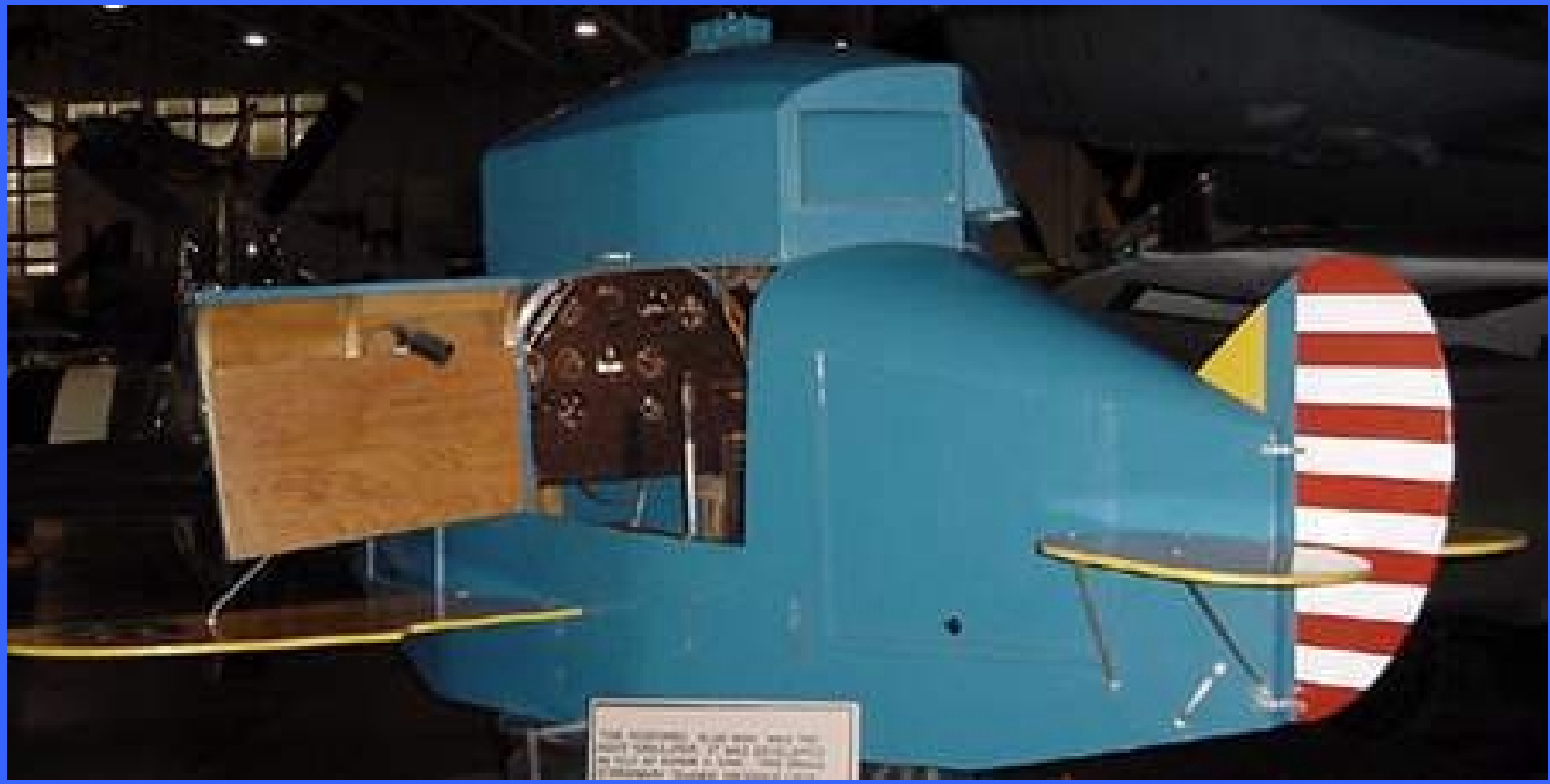
Development of Flight Simulators

Enter Ed LINK

- In 1928, Edwin C. Link, having learnt to fly, left his father's organ building business to begin work on a "pilot trainer."
- He envisioned a device that would allow pilots to take their preliminary flight instruction while safely on the ground.
- With his organ building experience, he used air pump valves and bellows to make his trainer move in response to its controls.
- In 1945, an AT-6 training airplane cost more that $10 per hour to operate. The Link Trainer cost $.04 cents an hour. 1/250 of the cost of aircraft training!

Development of Flight Simulators

Ed LINK's Blue Box

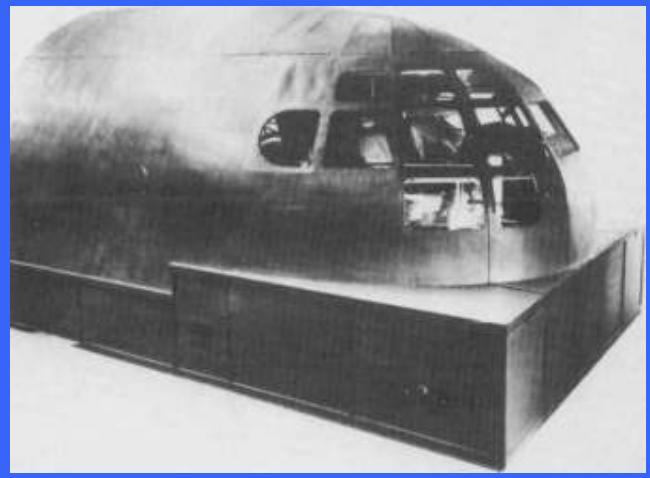


Development of Flight Simulators

Link *Trainer* – circa 1940
Limited pneumatic powered motion system in pitch, roll and heading and sound
General instrument flying trainer - not related to any aircraft type

Development of Flight Simulators

Curtiss-Wright were amongst the first to make Flight *Simulators* – such as for the B25 bomber



Actual aircraft Cockpits started to be used
1950s Boeing Stratocruiser – used by BOAC without motion nor visual

Current Simulators also have Motion and Visual Systems
1998 CAE A340 at Lufthansa Flight Training

Need for Flight Training?

"It's all automatic nowadays!!"

Landing technique that needs more practice…..?

Need for Flight Training?

Effect of a very hard landing *(done deliberately in flight test)*

Need for Flight Training?

Effect of a very hard landing *(not done deliberately!)*

Need for Flight Training?

Need for realistic handling in strong/gusty crosswinds……

Need for Flight Training?

Need for realistic handling in strong/gusty crosswinds……

Results can be expensive…..

Need for Flight Training?

Something to remember if you buy your own helicopter
(on the job training not appropriate)

Advantages of using Flight Simulators

Cost of Airbus/Boeing Flight Simulator approx US $17M / €15M £14M?

- **Cost -** ***(For Boeing 747 – Use of Full Flight Sim is over 40 times cheaper than aircraft)***
  - Aircraft always available for revenue service
  - Saving in fuel cost, landing and Air Traffic Control charges, positioning flights
  - Lack of wear and tear – landing cycles, tyres, engines at high thrust
- **Improved training**
  - Many failures cannot be carried out in the aircraft – fires
  - Many emergency procedures have too high risk on the aircraft – dual hydraulic failures
  - Abnormal weather and procedures can be experienced/practised – windshear
  - TCAS, GPWS and EGPWS warning can be experienced/practised
  - Any airfield in FFS and FMS database worldwide can be used – high altitude, latitude, etc..
  - Operation by normal crew, rather than with instructor in a pilots seat
  - Etc, etc
- **Lack of Pollution / Damage to the environment**
- **No use of valuable ATC slots**
- **Avoidance of training accidents**

(Training flights are a higher risk, but need not be unduly hazardous given sensible and competent training captains)

Advantages of using Flight Simulators

Flight Simulators are an essential part of the viability of ALL type of airline operations

easyJet.com

If airline training simulators are unusable, all operations will be severely curtailed within days

Essential Parts of a Flight Simulator

1. Computing systems – *without which nothing can happen*
2. Aircraft Flight Deck with sound system – *need alarms, etc*
3. Instructor Operating Station (IOS) – *a licensed instructor still essential*
4. Visual System
   a. Image generator
   b. Display system
5. Motion System
6. Sensible programme, competent instructors, certification and maintenance

Development of Flight Simulators

1. Computing systems

Computing capacity was unable to calculate the complete aerodynamic model of the aircraft and other systems

Aircraft handling largely relied on the subjective judgement of simulator test pilots *(often varied)* - and engineers' patience!

Engineers could "fly" the aircraft better than manufacturer's test pilots

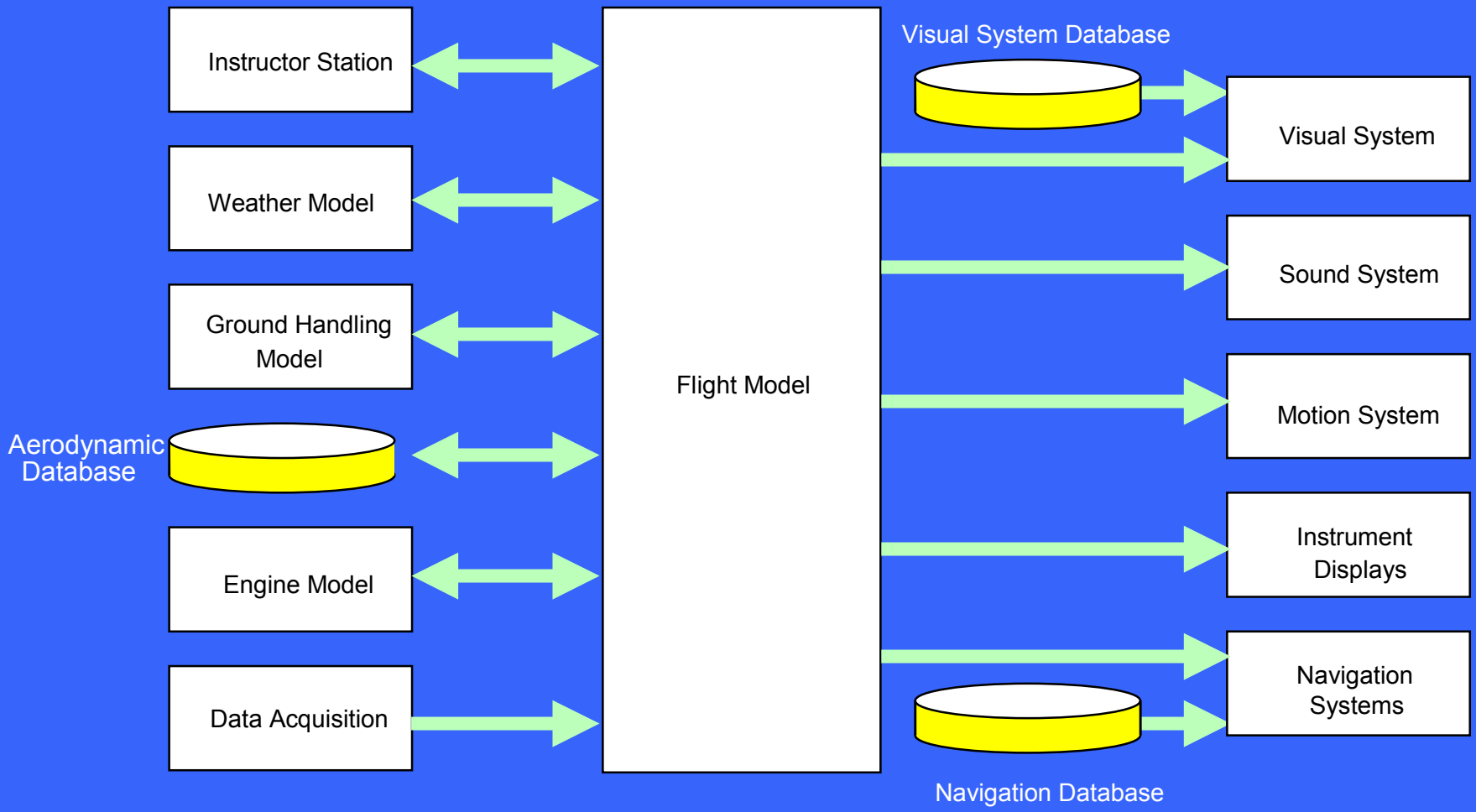
– Example; early SUD Caravelle simulator - which Chief Test Pilot crashed but simulator engineer could land!

Regular base flying on actual aircraft was still essential, with asymmetric / engine out training close to the ground required

Development of Flight Simulators

1. Computing systems

Digital computing led to aircraft controls and systems being run by computers and thus to the current simulator organisation



1. Computing systems

Tasks required by computing systems:

- **Aircraft handling, visual and motion systems**
- **All kinds of weather on the ground and in the atmosphere *and effects***
- **Ground terrain, buildings and radio aids**
- **Increasing number of aircraft navigational and other systems**
  - Flight Management Systems including radio, waypoints and terrain databases
  - Global Positioning System for navigation, GPWS & EGPWS warning systems
  - Windshear detection and avoidance systems / Head Up Displays
  - TCAS (Traffic Control & Avoidance System) / ACAS
  - Electronic displays fed by all the systems on the aircraft / Electronic Checklists
  - Video cameras giving views outside the aircraft for taxiing and inside the cabin

Then it must be able to:

- **Reposition aircraft and Flight Management Systems Instantly**
- **Allow failure of all significant systems with correct effects**
- **Instantly restore all failed systems to normal operation**

2. Aircraft Flight Deck

Easiest part –

From 1960s difficult to tell whether photograph of cockpit or actual aircraft

1971 First BOAC B747 digital simulator

THE ARGUS, THURSDAY, APRIL 29, 1971

COCKPIT of a B.O.A.C. jumbo jet. The autopilot controls for 'blind' landings can be seen on the panel immediately below the windscreen. Capt. Ken Loveless (left) and Senior First Officer Hugh Dibley try out the new machine.

Now should be impossible – without extremely detailed knowledge of specific aircraft type and model

1990s Airbus A330 cockpit – not known if aircraft or simulator

"Feel" of all flight controls must be indentical to the aircraft.

Simulators for Flight Training

3. Instructor Operating Station (IOS)

1940 Link Trainer Instructor Operating Station
Run by the instructor outside the cockpit
No View of Pilot's Operation – not suitable for assessing multi crew operation

Simulators for Flight Training

3. Instructor Operating Station (IOS)

The simulator is controlled by the instuctor through the IOS

- **Set up airfield, runway and weather**
- **Set up aircraft weight, fuel, configuration – doors etc**
- **Reposition aircraft on the ground and in the air**
- **Fail aircraft systems at appropriate times**
- **Restore systems, restart engines, reposition instantly**

Making these selections are secondary to the instructor's prime task

- **The instructors prime job is to monitor the crew's performance**
- **Diagnose crew problems and assist where possible**
- **Recognise the difference between minor slips and incurable incompetence**
- **If a "Check Ride" pass (or fail) crew and (not) revalidate licence**
- ***Remember the final outcome is safety and the lives of the public***

3. Instructor Operating Station (IOS)

The IOS controls the simulator through touch screens and push buttons.

- **The selections should be:**
  - Clear and instinctive
  - Avoid the instructor being distracted from monitoring the crew

Simulators for Flight Training

3. Instructor Operating Station (IOS)

- **Clear Layout and Content of Screens is Essential**

Where is the selection to push back from the parking stand?

Simulators for Flight Training

3. Instructor Operating Station (IOS)

- **Answer on the Services Page**

Simulators for Flight Training

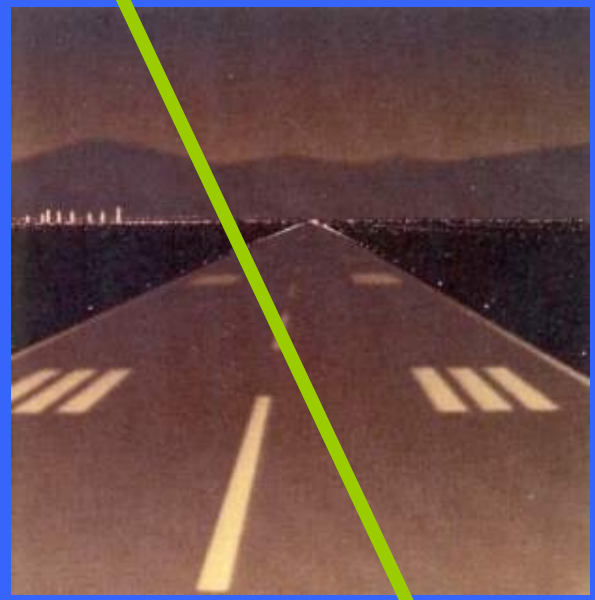
3. Instructor Operating Station (IOS)

- **Good Description and Position of Pre-Set Buttons also Essential**

Arrived Too High on Approach.

Need to hold aircraft in that position to discuss why.

Press HOLD POS button



Aircraft rapidly put back on ground, in runway HOLDing POSition!

(Should have pressed* POS FREEZE *below)

Simulators for Flight Training

3. Instructor Operating Station (IOS)

1999 - Thales, Crawley, A320 Forward Facing IOS

Screens in front of Instructor, but head movement required to scan both screens.
Two A4 writing surfaces on arm rests, with stowages behind.

Simulators for Flight Training

3. Instructor Operating Station (IOS)

IOS produced by Reflectone (now CAE) based on requirements from Airbus Toulouse instructors

On Left :
Radio Panel, Writing Surface and Stowage

On Right :
2 Screens, one above the other, Movable Table and Stowage

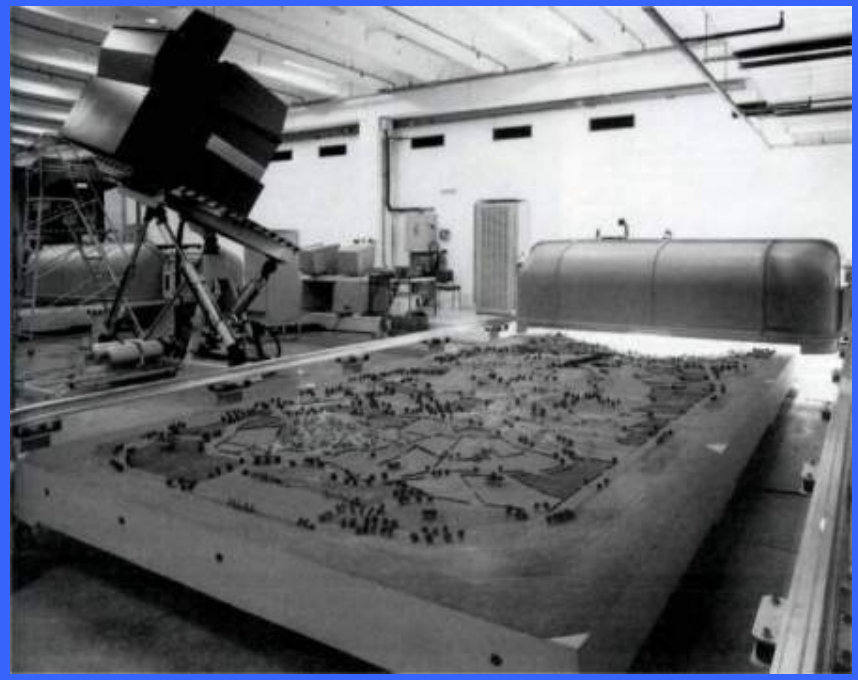
Simulators for Flight Training

3. Instructor Operating Station (IOS)

Thales 777 IOS

Development of Simulation
4. Visual Systems

a. Image Generators – Examples



1960-70s
TV camera over model boards

1978
Computer Graphics

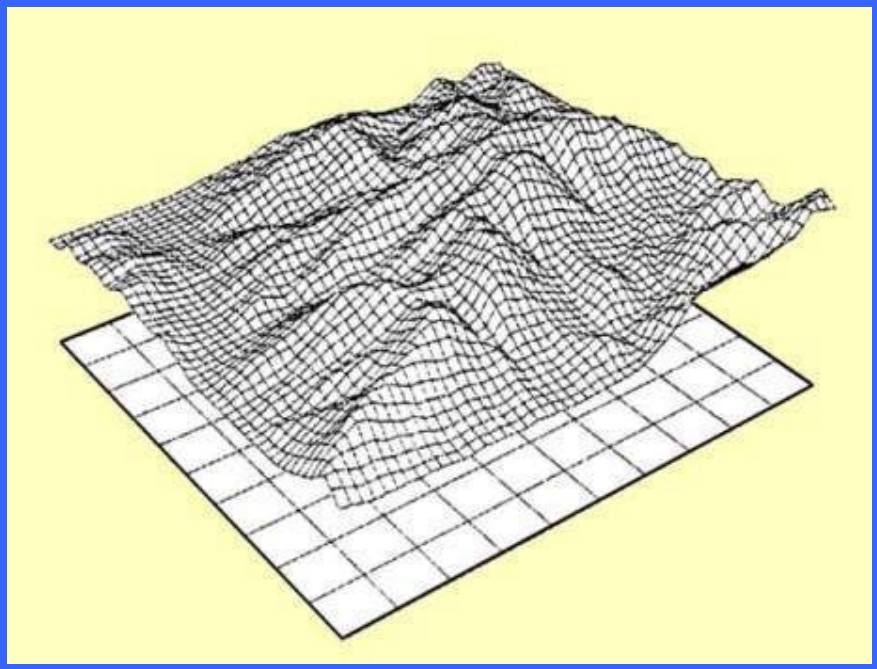
Development of Simulation
4. Visual Systems

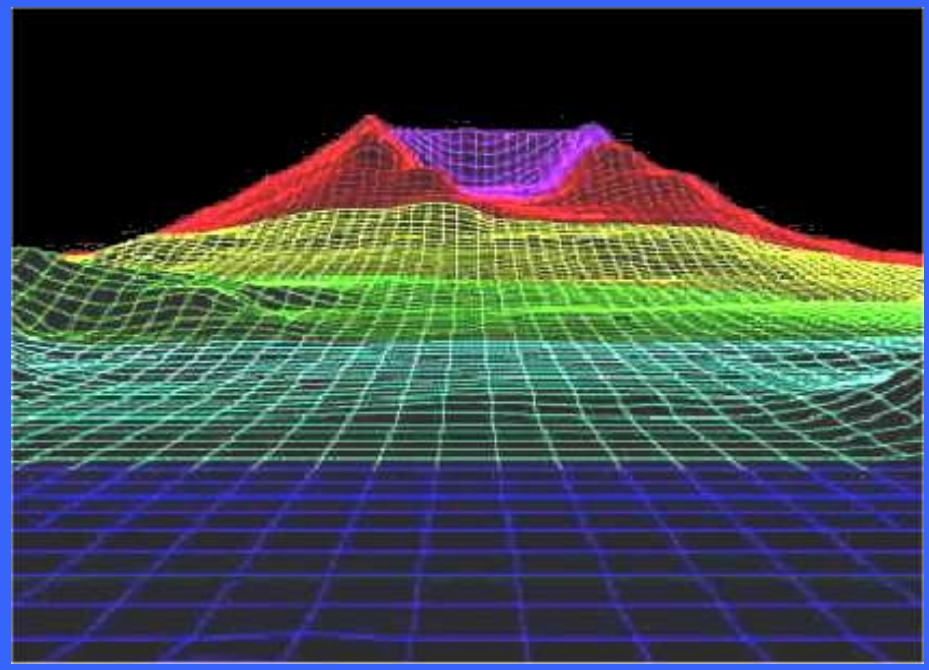
a. Image Generators – Examples

Current image generation quality
Large improvements have been due to games software

Development of Simulation
4. Visual Systems

a. Image Generators – 3 D Imagery



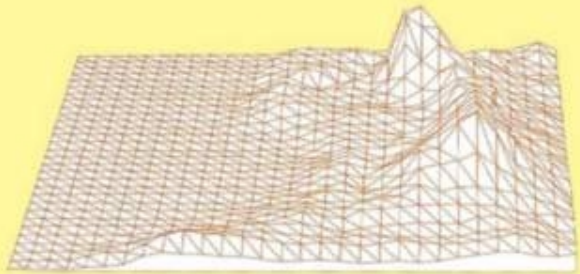


Two examples from US National Imagery and Mapping Agency (NIMA)
Height resolution shown by size of squares
Morphing (averaging) algorithm to remove sharp edges

Development of Simulation

4. Visual Systems

a. Image Generators – 3 D Imagery



1. Edited flat features 2. Height grid 3. Feature draped over grid

(CAE, Montréal)

Development of Simulation

4. Visual Systems

a. Image Generators – Imagery or Photo?

Sydney Harbour (by Transas, UK/Russia)

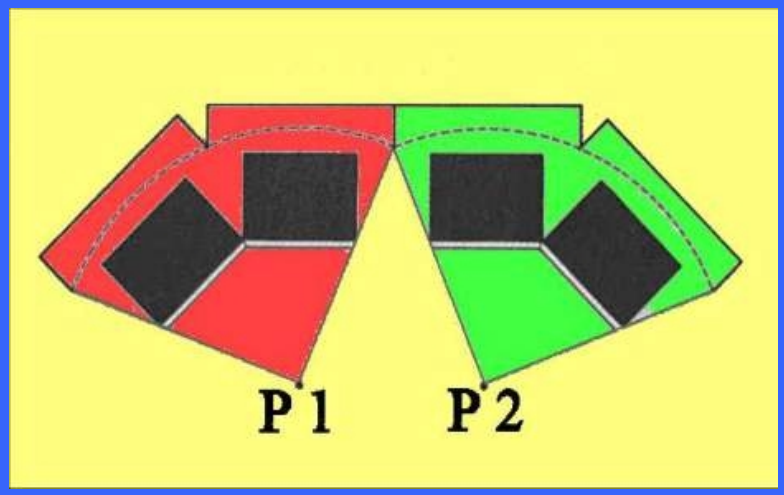
4. Visual Systems

b. Display systems

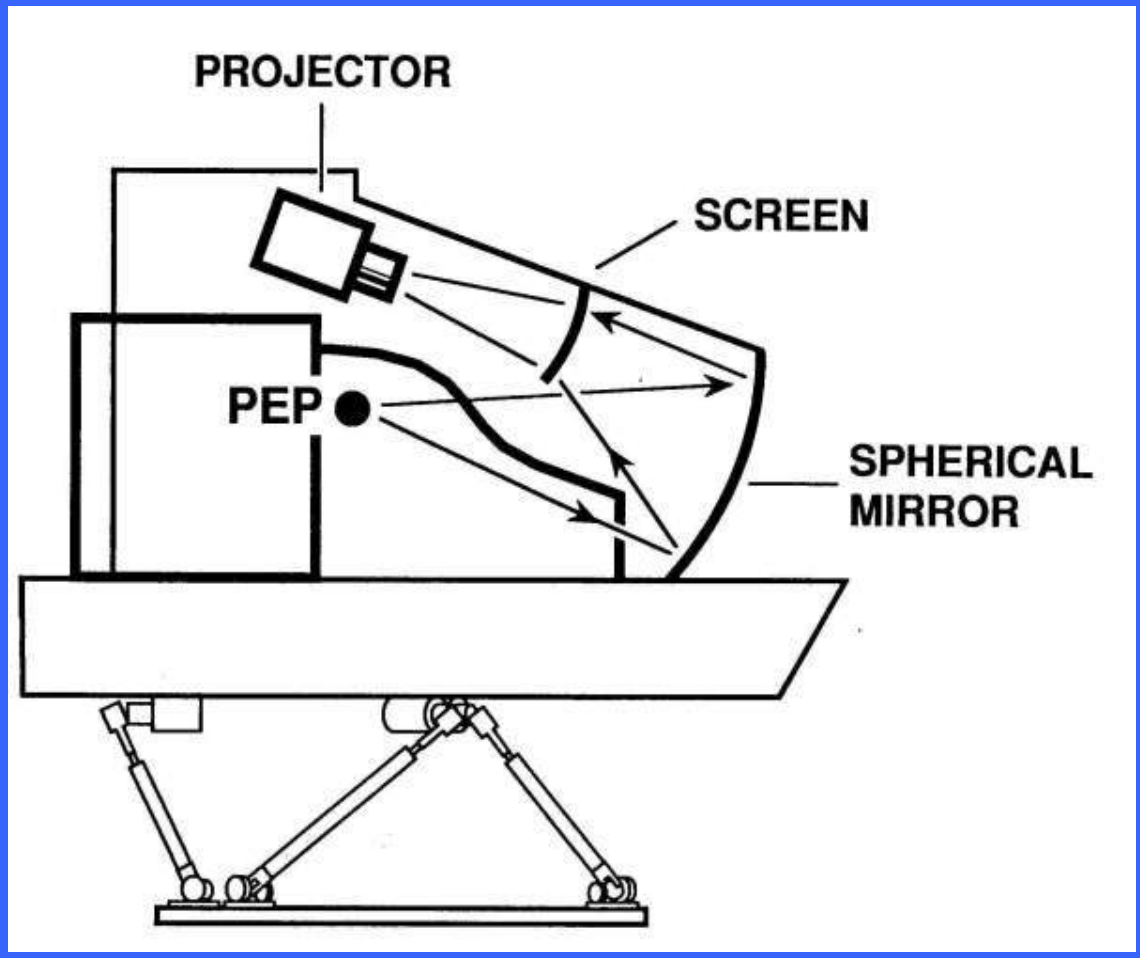
Civil Flight **Simulator** "Levels"

Outside World (OTW) Visual:

Levels A/B	Levels C/D
Min 45 x 30°	150° (H)
per pilot	collimated (distant focus)



b. Display systems



Projection system

b. Display systems

Cross-cockpit Collimated Systems

Distant focus through intermediate screen & curved mirrors

allows un-restricted cross-cockpit viewing

Theory and reality

(Sim by CAE, Canada)

4. Visual Systems

b. Display systems

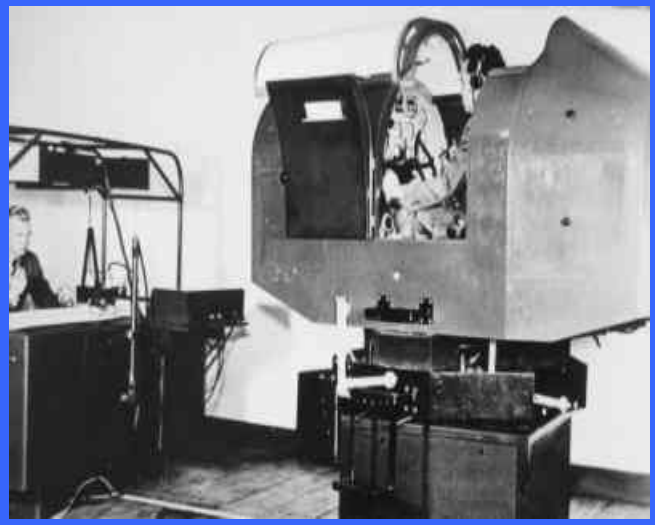
Mirror is a flexible Mylar sheet kept in place by suction – no suction here so distorted

Development of Simulation

5. Motion Systems

Examples of early Flight Simulator Motion Systems

1909 - Antoinette (human-operated half-barrels)



1930 - Link trainer (pneumatic platform)

1932 - USAF Brooks AFB, (human-operated gimbals)

Development of Simulation

5. Motion Systems

Examples of Motion Platforms in the simulation industry

Ground vehicle

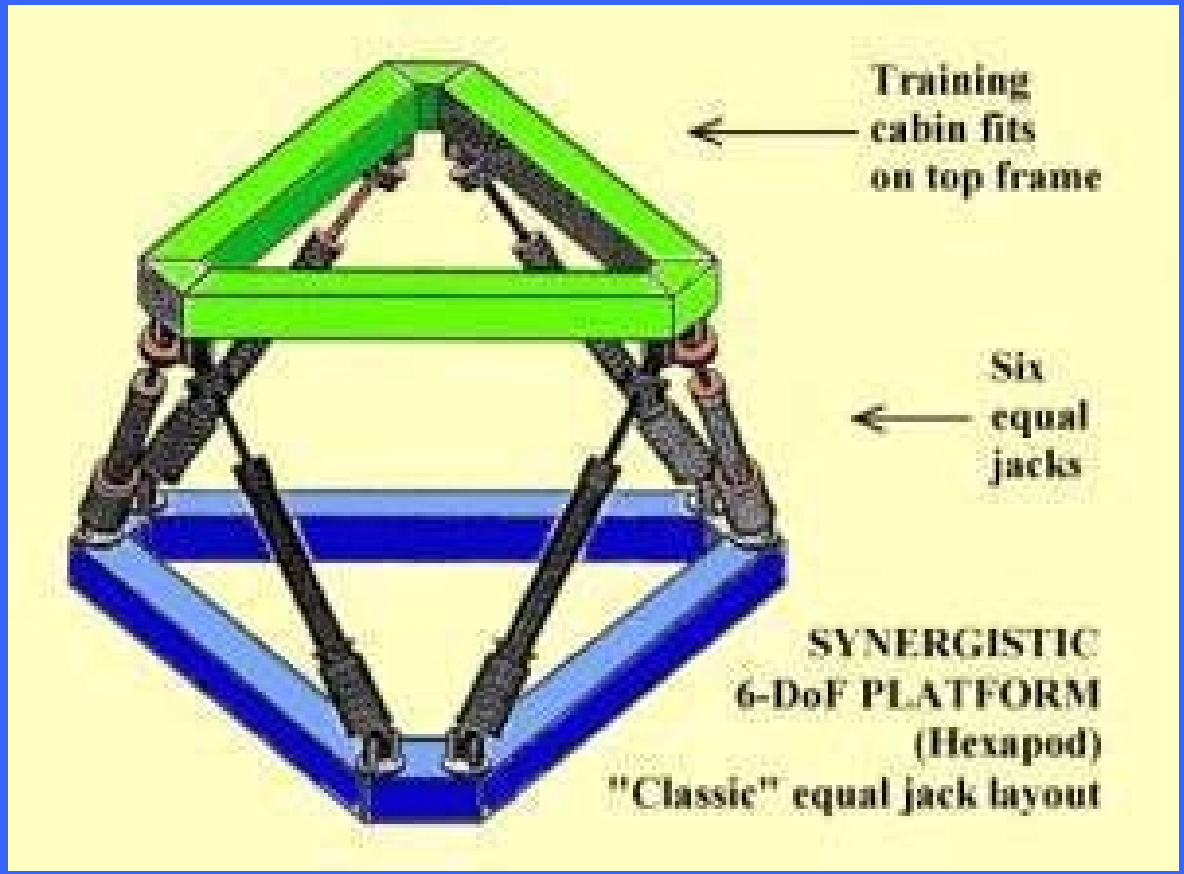
Ship's bridge

Aircraft

Small, large – electric, hydraulic

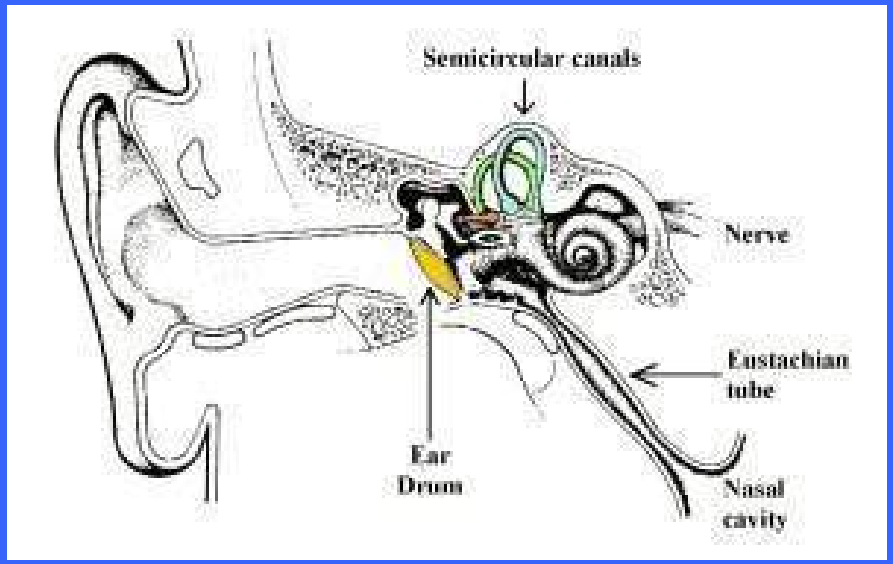
Development of Simulation
5. Motion Systems

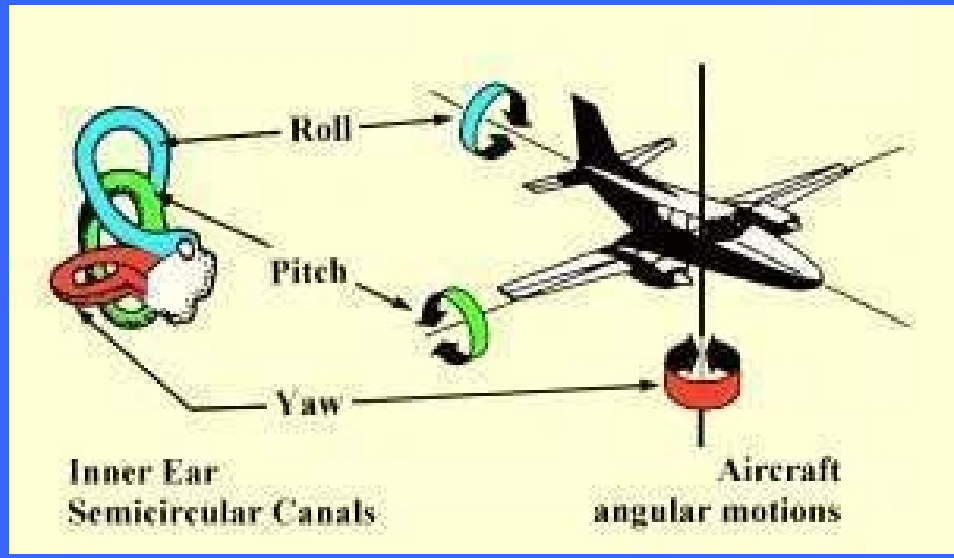
Current motion platform used in most simulators



5. Motion Systems

Angular motions are sensed in humans by canals in the inner ear

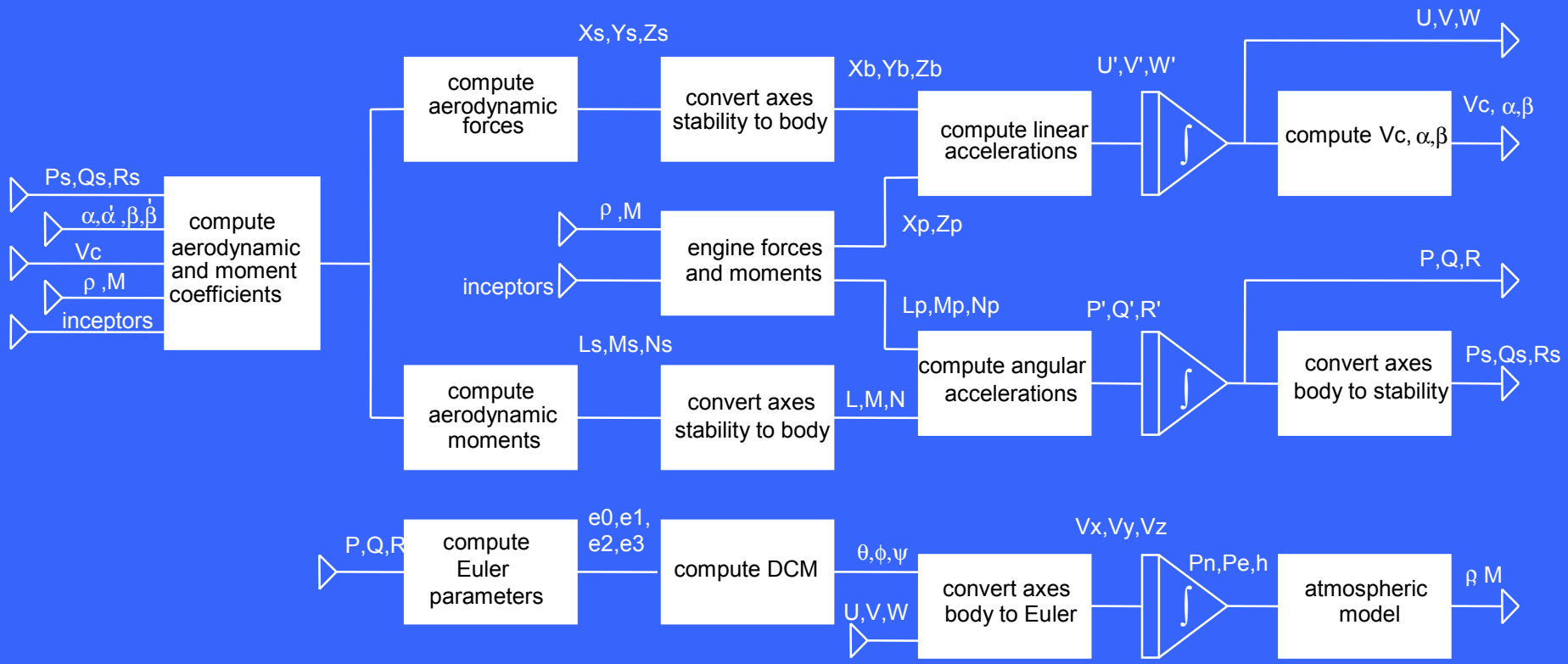




Development of Simulation

5. Motion Systems

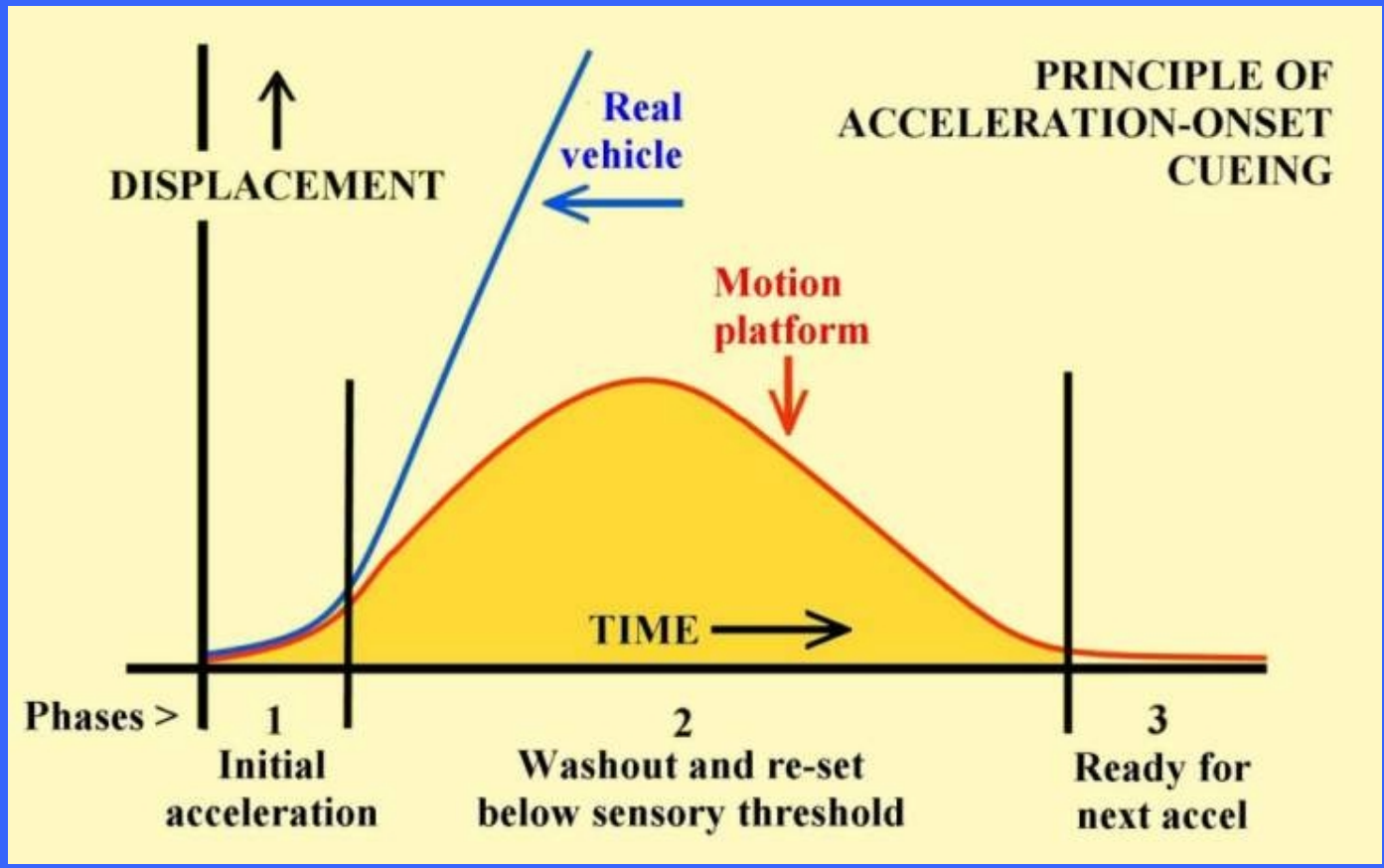
The inputs to the motion platform are calculated by the Equations of Motion



Development of Simulation

5. Motion Systems

As movement is limited, platform motion must be washed out ready for next event

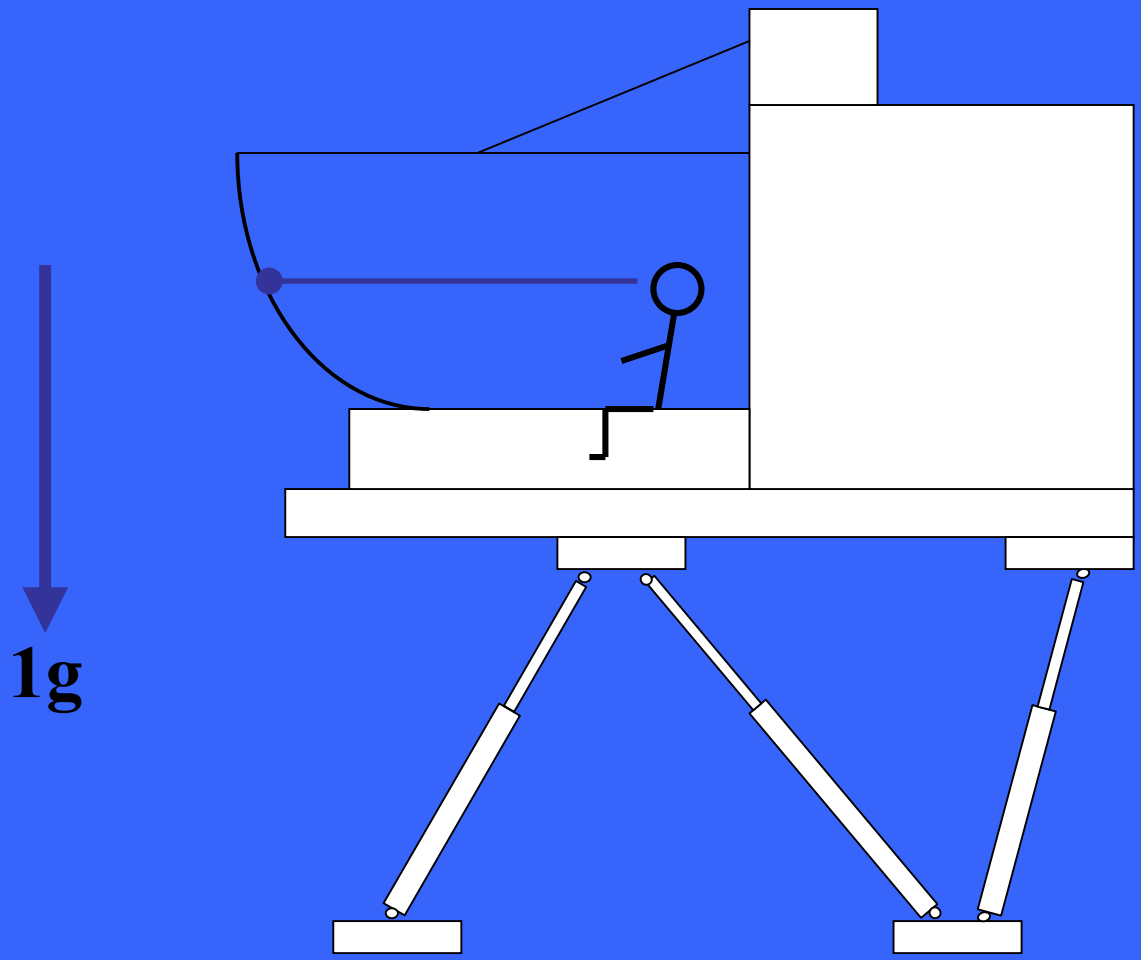


Centrifuges are needed for high G acceleration *(seen only in civil aircraft rejected takeoffs)*

Development of Simulation

5. Motion Systems

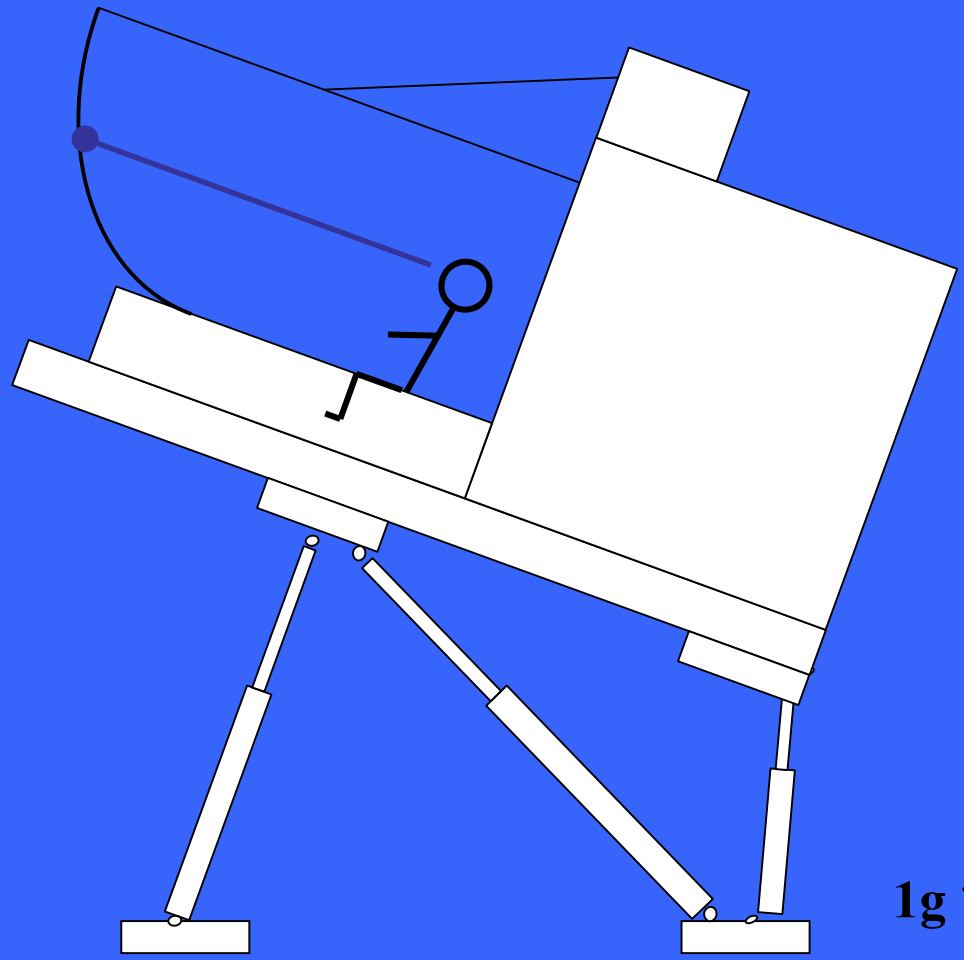
Acceleration sense available from motion platform



Development of Simulation

5. Motion Systems

Acceleration sense available from motion platform



1g

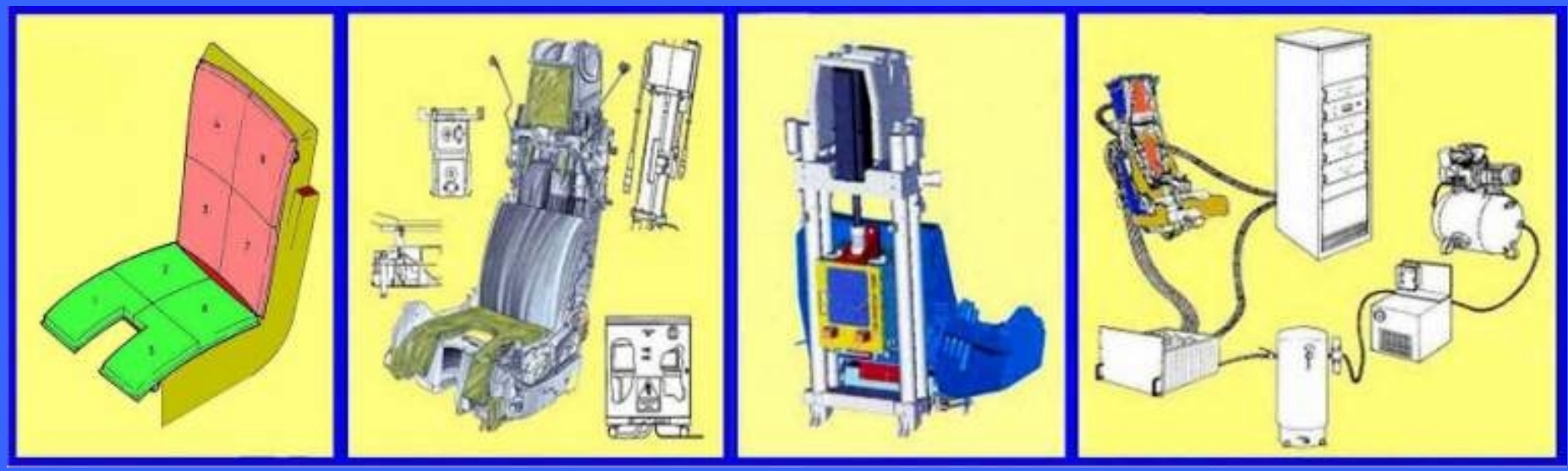
1g * Sin 20° = 0,34 g

20°

1g * Cos 20° = 0,94g

5. Motion Systems

The are other systems – some cheaper
Simulator Motion Seats / G-Seats



Facilities include: Anti-G suit inflation, seat pan lowering, strap tightening, pressure pads (seat, back). Movements, vibration, etc.

Development of Simulation

5. Motion Systems

Examples of High G Motion Systems *(not needed for civilian FFS)*

Man-rated Centrifuges

by AMST (Austria), Latecoere (France)

Environmental Tectonics (ETC) and Wyle (USA)

Development of Simulation
Other Training Devices

For Maintenance Training






Manufacturers include aircraft manufacturers and:

AAI (USA), BAES Insyte (UK), Atlantis (Can), Boeing (USA), CAE (Can, Germany, USA), ECC (USA), ETC (USA), Link (USA), Pennant (UK), USM (USA), Vega (UK)

Development of Simulation
Other Training Devices

MFTD (Maintenance & Flight Training Device)

CAE Simfinity Integrated Procedures Trainer

Used by Airbus for Flight Crew Training before Full Flight Simulator Training
ore effective FMGS & Cockpit setup training using "Learning By Doing"
Time in expensive FFS concentrates on handling and can be reduced
Must have same integrity as FFS
Contains identical software as aircraft and FFS through Top Down development

Development of Simulation
Other Training Devices

A380 MFTD

Development of Simulation
Need to Standardize Training Devices
RAeS Flight Simulation Group
International Working Group

Up to 1980s simulator manufacturers tended to build Flight Simulators to their latest technology, then offer to operators who agreed training benefits from their Authority.
THERE WERE NO INTERNATIONAL STANDARDS.

RAeS Flight Simulation Group formed in 1970s
Run by multi-national Committee –
Wolf-Dieter HASS Lufthansa Flight Training long term member and Chairman 2004-2006.

1992 Produced International Simulator Qualification Test Guide (IQTG) approved by FAA & JAA & published by ICAO for TOP LEVEL FFS.

2005 At the November conference Dr Ed Cook suggested the RAeS set up a group to standardised ALL Flight Training Devices

2006 International Working Group formed - 60 delegates/16 countries

2008 In April produced final draft of ICAO 9625 -
'Manual of Criteria for the Qualification of Flight Simulation Training Devices'
Volume 1 (Fixed Wing) – Volume 2 (Rotary Wing) will follow in some 18 months

Development of Simulation
Need to Standardize Training Devices
RAeS Flight Simulation Group
International Working Group

International Working Group Assessed Training Requirements & Assigned Level of Training Device Needed to Obtain Training Credits

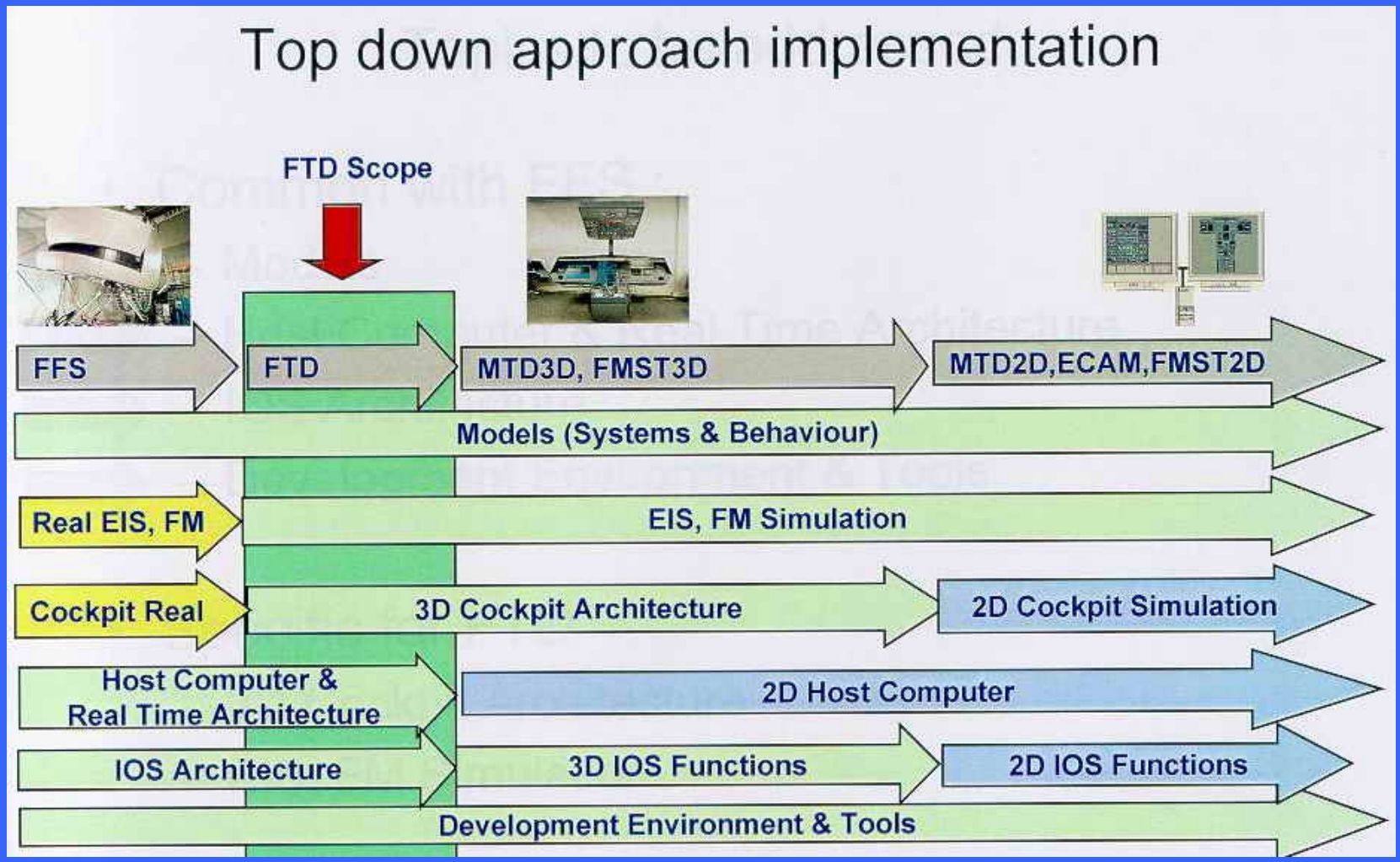
Volume 1: Some High Level Requirements

	Lvl 1	Lvl 2	Lvl 3	Lvl 4	Lvl 5	Lvl 6	Lvl 7
	T - PL, MPL1, CPL	T - IR	T - CR	TP - MPL2	T - TR, RO	TP - MPL3	TP - TR, RL, RO, MPL4 T - Re
Cockpit	Class Representative Enclosed Cockpit, Linings, Window Geometry				Aircraft Replica Enclosed Cockpit, Linings, Windows		
Instruments & Panels	Flat Panel & Overlay				High Quality Flat Panel & Overlay		• Full (3D) Replication
NSA	Open				Enclosed		
Visual Disp.	200 x 40 Direct	45 x 30 Flat Screen	200 x 40 Direct			200 x 40 Collimated	
Motion	None					Reduced 6 DOF	
Flight & Flight Cntrl	Class repres.	Generic	Class repres.	Generic	Aircraft Specif		
A/C Systems	Aircraft Representative (Required Procedures)				Specific (All Proc.)	Specific (Req Proc)	Specific (All Proc.)
ATC	None	Chatter + Comm	None	Chatter + Comm	Chatter + Comm (correlation with visual)	• Dynamic Automated Environment (for MPL phases 3 & 4)	

Including MPL requirements

Engineering Simulators
A further way of achieving standardization

Airbus Type Top Down System Ensures Fidelity of All FTDs

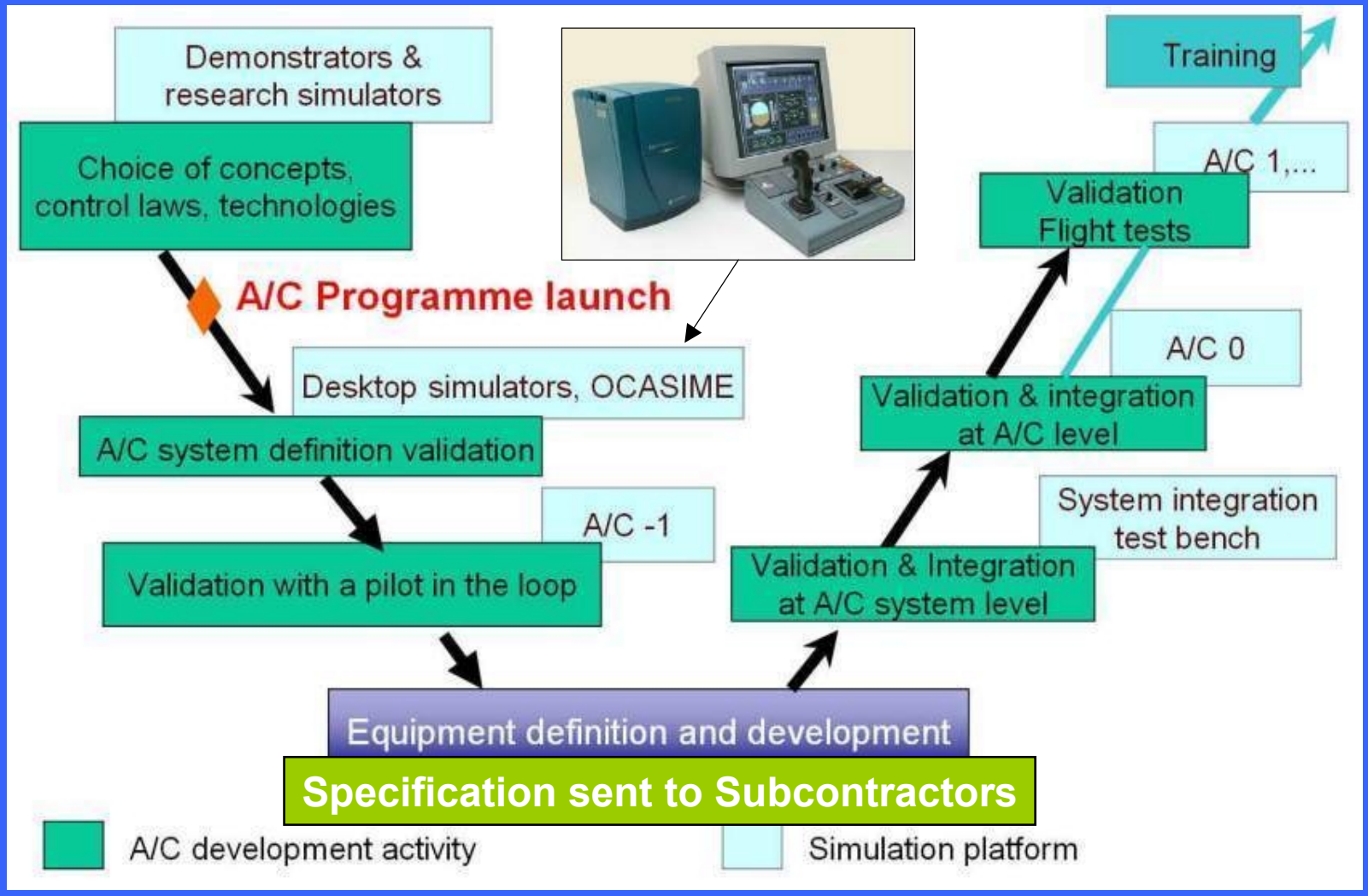


On latest aircraft, all software is developed from Engineering Simulator / Iron Bird

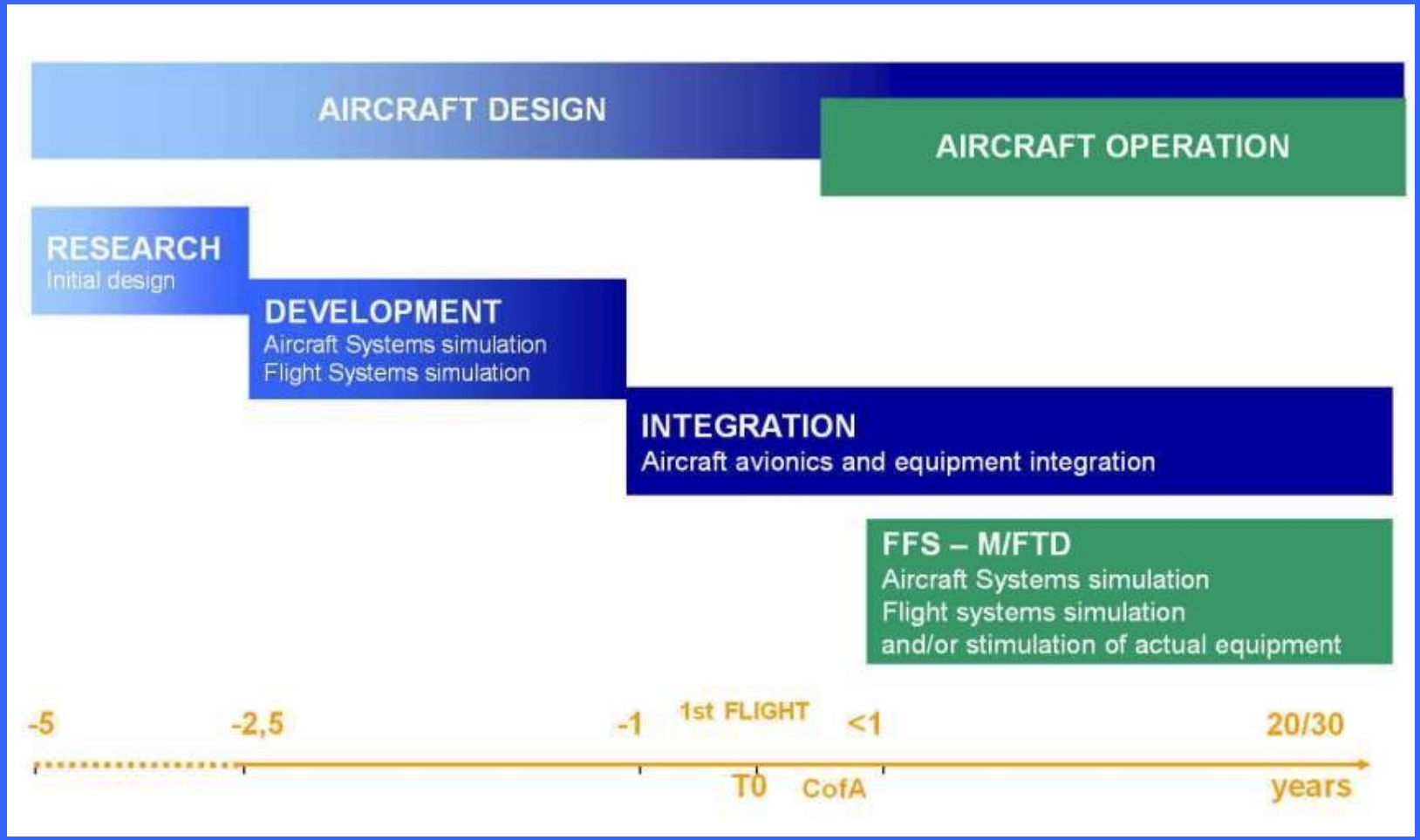
Engineering Simulators
Airbus A380 Iron Bird

Airbus aircraft software development:

Concept, system validation, definition, integration, flight test validation, release for training



Engineering Simulators
Airbus A380 Iron Bird
Engineering Simulation Timescale



A380 Iron Bird is planned to run for at least 25-35 years

Engineering Simulators
Airbus A380 Iron Bird

Engineering Simulators
Airbus A380 Iron Bird

A380 Iron Bird visual system on platform – can be "hover-crafted" to the 4 cabs

Engineering Simulators

Airbus A380 Iron Bird

4 A380 cabs / flight decks.

From the left Aircraft: -1 for Development, 0 for Systems Integration & 2 spare

The 2nd and 3rd cabs from the left can control the actual aircraft hardware in the Iron Bird systems hall

Engineering Simulators

Airbus A380 Iron Bird

A380 System Hall

All hydraulic flight control and undercarriage systems exactly as per real aircraft

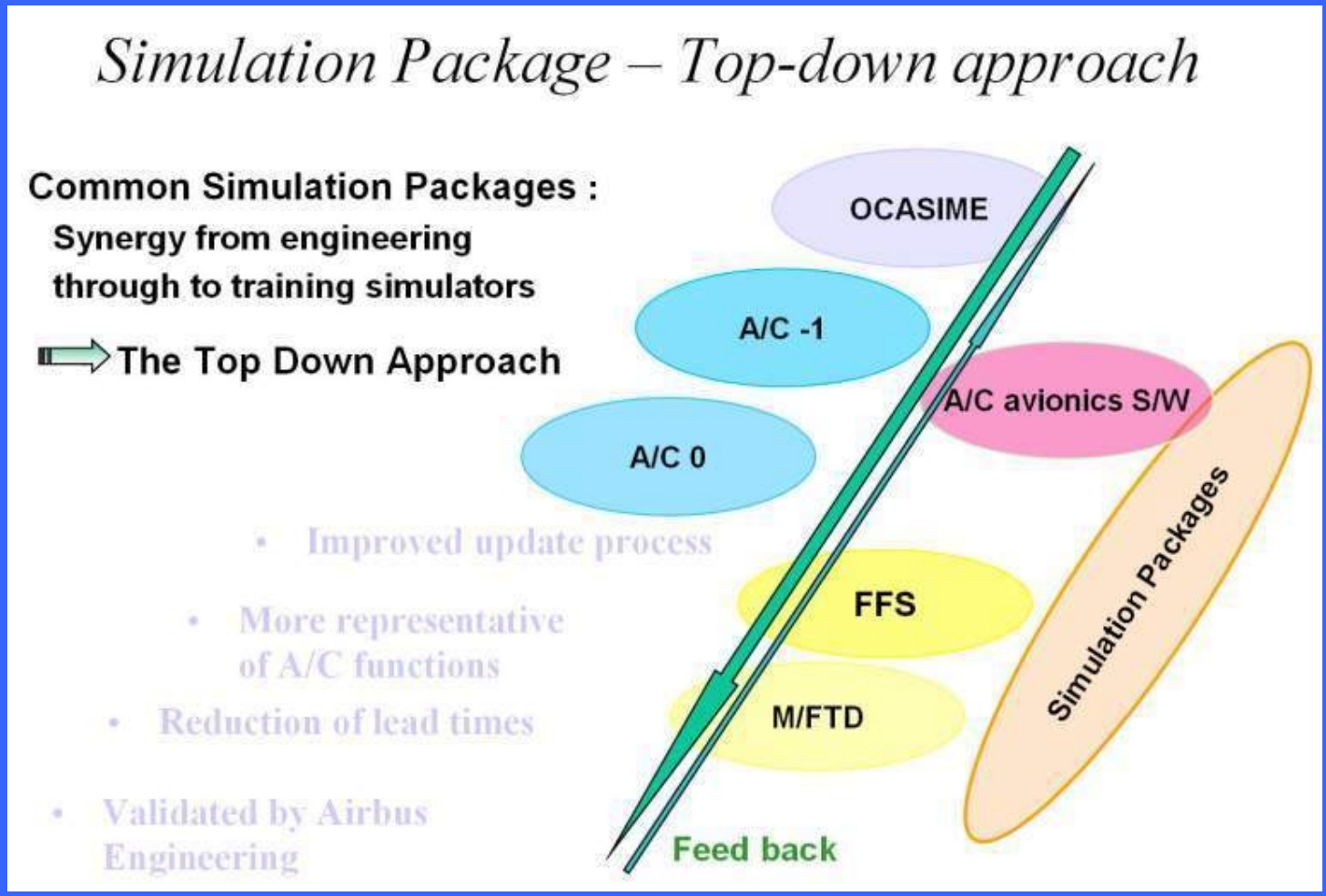
View from top of aircraft's vertical fin / rudder, looking along the fuselage.

Wings are folded back parallel to the fuselage

View from right front of aircraft looking towards the vertical fin / rudder.

2 engine pylons extend out to the left of the right wing (ending in brown colour).

Engineering Simulators
Airbus A380 Iron Bird
Summary of Airbus Engineering Simulation Process



Where is aircraft 1?

Engineering Simulators
Airbus A380 Iron Bird

Aircraft 1 is where virtual becomes reality
Many tests can only be done on the aircraft…..

But the aircraft is linked forever to the iron bird.....

In Test Flights all systems are connected by video link and monitored by an Iron Bird team

The Iron Bird is expected to be in service to develop / improve the A380 for over 35 years

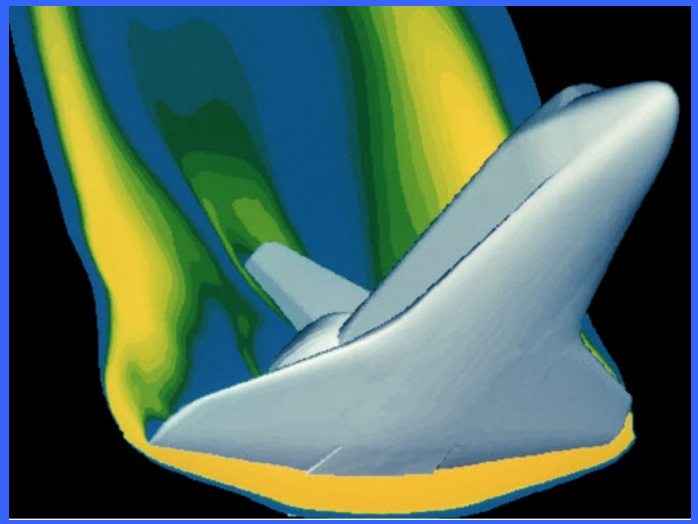
Other Rigs Ground Simulators

Rig/simulator to test A380 wheel loads while taxiing

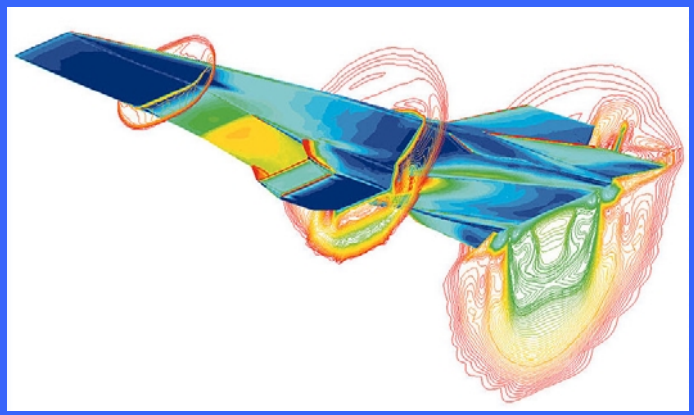
Other Airbus Rigs/simulators are at:
Hamburg – cabin and flaps/slats
Filton – under carriage/gear and fuel system

Flying Test Beds – For Engines
Another of form of Simulation?

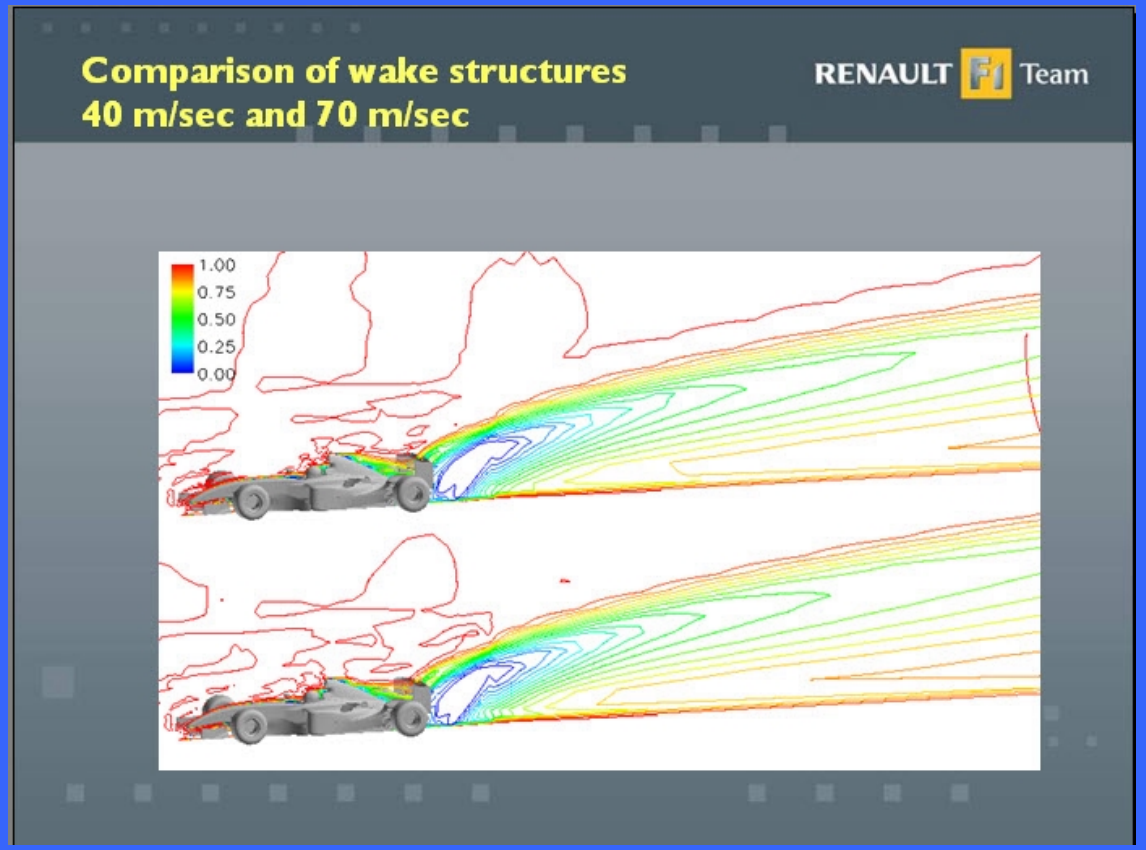
Computational Fluid Dynamics now used to Simulate Aerodynamics in Many Areas



Computer simulation Space Shuttle air flow during re-entry



Hyper-X scramjet at Mach-7



But Aerodynamic Simulation still confirmed in Wind Tunnels

Space Flight Tourism Simulation

The 2 Virgin Galactic Space Ship 2 pilots train on a Scaled Composites Engineering Simulator - without motion

Space Flight Tourism Simulation

The 2 Virgin Galactic Space Ship 2 pilots train on a Scaled Composites Engineering Simulator - without motion

Space Flight Tourism Simulation

On return from its mission to launch Space Ship 2 the White Knight Mother Ship can make several approaches to train Space Ship 2 pilots for their glide approach – with normal motion and visual!

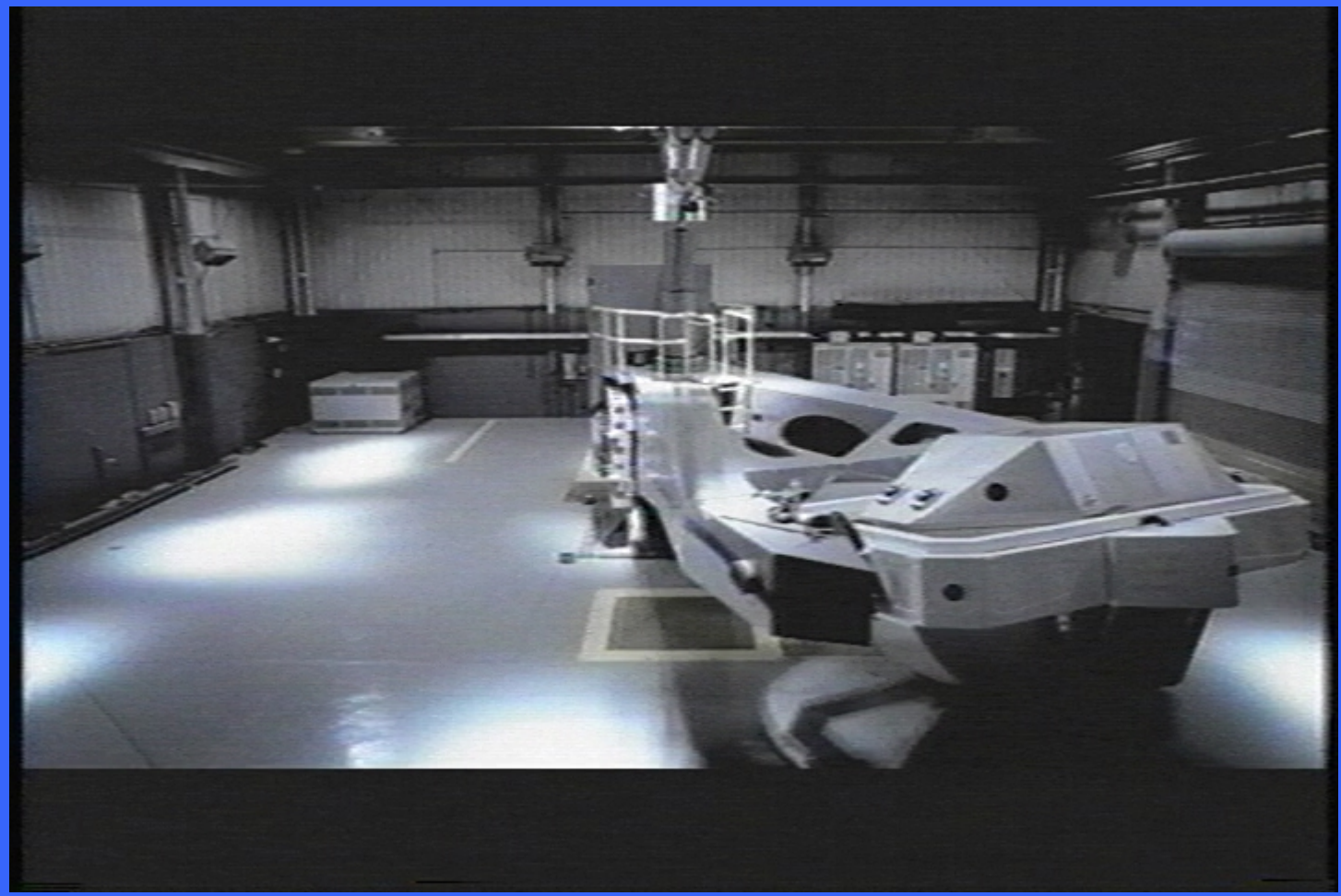
Space Flight Tourism Simulation

But prior to their space flight – passengers must experience the forces experienced up to 4 G during acceleration and deceleration…..

In a NASTAR Centrifuge

Space Flight Tourism Simulation

But prior to their space flight – passengers must experience the forces experienced up to 4 G during acceleration and deceleration…..



Many different types of equipment & roles/aims






Military Simulation

Need for some form of High G Motion Systems

Centrifuge for Swedish Air Force
by Wylie Laboratories, Los Angeles

"G-dimming" visual effects

G-dimming on simulator Image Generator

Note loss of colour and lower pilot position in seat

At computed G approaches 9, imagery dims, then goes monochrome, then tunnel vision, then black.

Low-cost (may be no-cost) addition to Image Generator.

Fitted to Eurofighter Typhoon sims and Others

but not in F-22 Raptor sims or others in USA

Big use of Military Simulation……

Multi-sim Multi-role exercises (Air/Air & Land/Sea/Air)

Tactical Control Centre (TCC) - the key to war gaming

Military Simulation

Whatever the role - similar suite of training devices as in civil aviation

Flight Simulation Lecture Achievement?

Reassured you that airline crews can deal with possible difficulties…..?

Flight Simulation Lecture Recommendation?

Always fly First Class!!

Thank you for your attention!