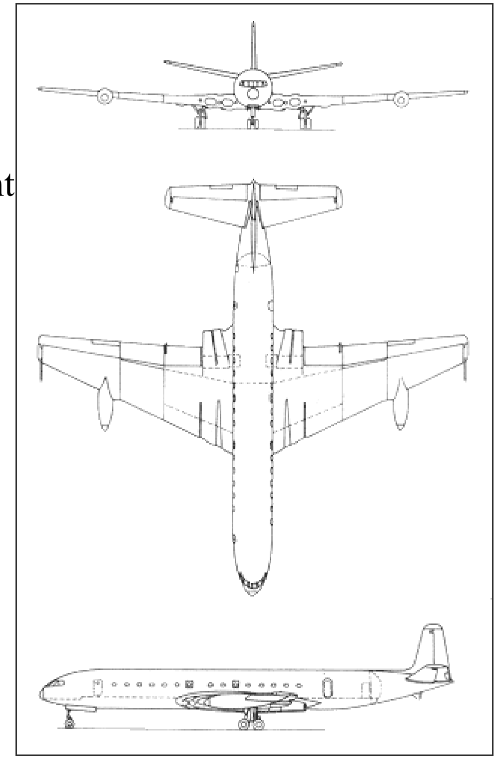
The Redifon Comet 4 Flight Simulator for BOAC



The Comet 4 entered service with BOAC in October 1958 with simultaneous departures from London and New York. Earlier that year the airline contracted Redifon to build a flight simulator with a motion base, an advance on the fixed base simulators in use until then.

Eur Ing Kenneth J Wheeler CEng MIMechE FCMI CDip (ACCA) was Chief Mechanical Engineer at Redifon at the time. He designed the motion system for the BOAC Comet 4 Simulator and has written about it for us. Ken retired as a Managing Director in the Norris Group of companies some 22 years ago.

For a brief history of flight simulation, click on the link below:
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.132.5428&rep=rep1&type=pdf

With the introduction of the Comet, BOAC decided that a fixed base simulator, which was the norm at that time, was inappropriate for a jet propelled commercial airliner as sensory cues brought about by physical motion in the pitching mode were necessary to match the instrumentation. A contract was awarded to Redifon in 1958 to supply a Comet 4 simulator with motion in the pitching plane. There was no such thing as visual aids at that time such that pilots were flying the simulator by instruments only. The simulator would have a pitching angle of 12 degrees up and 17 degrees down about a defined fulcrum with tailored displacement, velocity and acceleration rates determined by the analogue computer's flight control system matched to the instrumentation on the flight deck. The artefact was to utilise a forward section of a Comet 2 from the de Havilland production line with its interior upgraded to the standard of the Comet 4. This forward section via a support structure was mounted on an angle iron frame with its pivot bearings aft (fulcrum) to realise the pitching motion. In the dormant state the fuselage was held horizontal by the rotating arm roller engaging the claw on the support structure. Electrical connection to the instrumentation was via a "waterfall" from a distribution panel behind the simulator over the fulcrum then on to the flight deck.

It is important to realise that these were the days when digital computing was in its infancy and not applied to flight simulation, the flight control computer being analogue as would be any electro hydraulic servo system designed to serve the motion.

It was known that an electro hydraulic valve and actuator combination as a high fidelity position servo mechanism in common use to power, say, flight controls produces a "harsh" output in response to electrical signals quite unlike the "soft" response of an aircraft in pitch. The Comet 4 has a pitching natural frequency of about 1.5 Hertz. Pumping oil across a double-acting hydraulic servo actuator using a variable displacement swash plate pump in series with a high fidelity position servo mechanism receiving a syncro (magslip) signal from the flight computer with a low gain position feedback signal from the fuselage support structure provided the solution required. The double acting servo actuator was precharged at 50 psi through check valves on both sides to exclude air at all times using a separate hydraulic system. The fuselage section employed was mounted on a substantial welded steel plate support structure secured forward in the undercarriage mounting brackets and aft by shear plates multi-bolted to the fuselage floor.

The weight moment of the forward fuselage section was counterbalanced about the pitching fulcrum by a series of substantial cast iron weights set aft. In this way the servo actuator driving the motion was subjected to uniform forces in each direction of an inertial nature and thus similar dynamic response. With the system shut down the support structure was secured by a rotating arm roller engaging with a claw on the support structure; the rotating arm was powered by a separate hydraulic system whose actuator contained an internal mechanical locking mechanism which locked the arm into the claw when shut down. The servo actuator had a custom designed bypass valve connecting both sides which was actuated by the rotating arm roller entering the claw.

Analogue closed loop position servo systems inherently have a fault condition where loss of the outside feedback signal can result in a runaway to one extreme of the available movement at considerable speed with consequent mechanical damage to the installed apparatus. To obviate this a DOWTY liquid spring was fitted to each end of the motion stroke.

Continued on next page.

Flying the Comet 4 Simulator

The simulator was originally built for BOAC in 1958 and sold on to Dan-Air in 1970. It passed into the hands of the Science Museum at Wroughton in1988 having amassed a total of 10660 training hours; surely a record. The de Havilland Museum acquired the simulator, less the computer, in 1966, stripped it of its motion system, much to the chagrin of the author, and placed the fuselage section on a static stand. Thompson Simulation, who succeeded Redifon, told the author that no Comet data had been archived. As stated earlier the simulator installation predated the time when visual panoramas were available and its use was primarily to instruct the flight deck crew on emergency procedures rather than how to fly the aircraft manually on instruments.

The onset of flying commercial aircraft at high speed and altitude due to the introduction of the Comet led to the need to understand the implications of "coffin corner" where stalling speed and the speed at the limiting Mach number meant that for the Comet at 40000 feet, the margin was as small as 20 knots. Exceeding the maximum operating Mach number for the Comet which is 0.8 M causes the aircraft to pitch violently downwards(called Mach tuck) probably into an irrecoverable scenario. It is not known by the author whether this was practised on the simulator but the specification requirement for 17 degrees nose down must to have been for some reason.

Digital computing has changed everything. With the invention and adoption of the Stewart variable motion system and flight design by programmers using machine code to replicate flight data provided by the plane's maker over the internet it seems that the engineering has sort of been taken away.

Ken Wheeler CEng, October 2016
k.wheeler865@btinternet.com

Photos and diagrams

Fig 1 BOAC Comet simulator installed at Cranebank ,Heathrow 1958
Fig 2 Simulator at Redifon in dormant state
Fig 3 Illustration of simulator in pitch up mode
Fig 4 Illustration of simulator in pitch down mode
Fig 5 Details of motion control mechanism
Fig 6 Schematic of pitch motion servo control loop
Fig 7 Schematic of hydraulic control system

Comment by Roger de Mercado:
The Comet did have a moderate nose down trim change at high Mach No. To counteract it a step change of nose up trim was applied just beyond the maximum operating Mach No. There was a gearing change between low speed and crusing speed in order to make control column movement less sensitve at high speed. This was a simple mechanism and the Mach trim input applied a bias to it. Failure was improbable and it is unlikely that there was a training scenario about it. However the Comet was the first airliner to operate at high altitude (up to 42,000 ft) and pressuruisation failure required an expedited emergency descent unfamiliar to pilots used to cruising around 25,000 ft. The nose down pitch attitude in emergency descent is typically around 10 deg. and this may be why BOAC specified the extreme nose down attitude of 17 deg. It is not known to what extent use was made of pitch attitude to represent acceleration and deceleration on this early device.

FIG 1

FIG 2

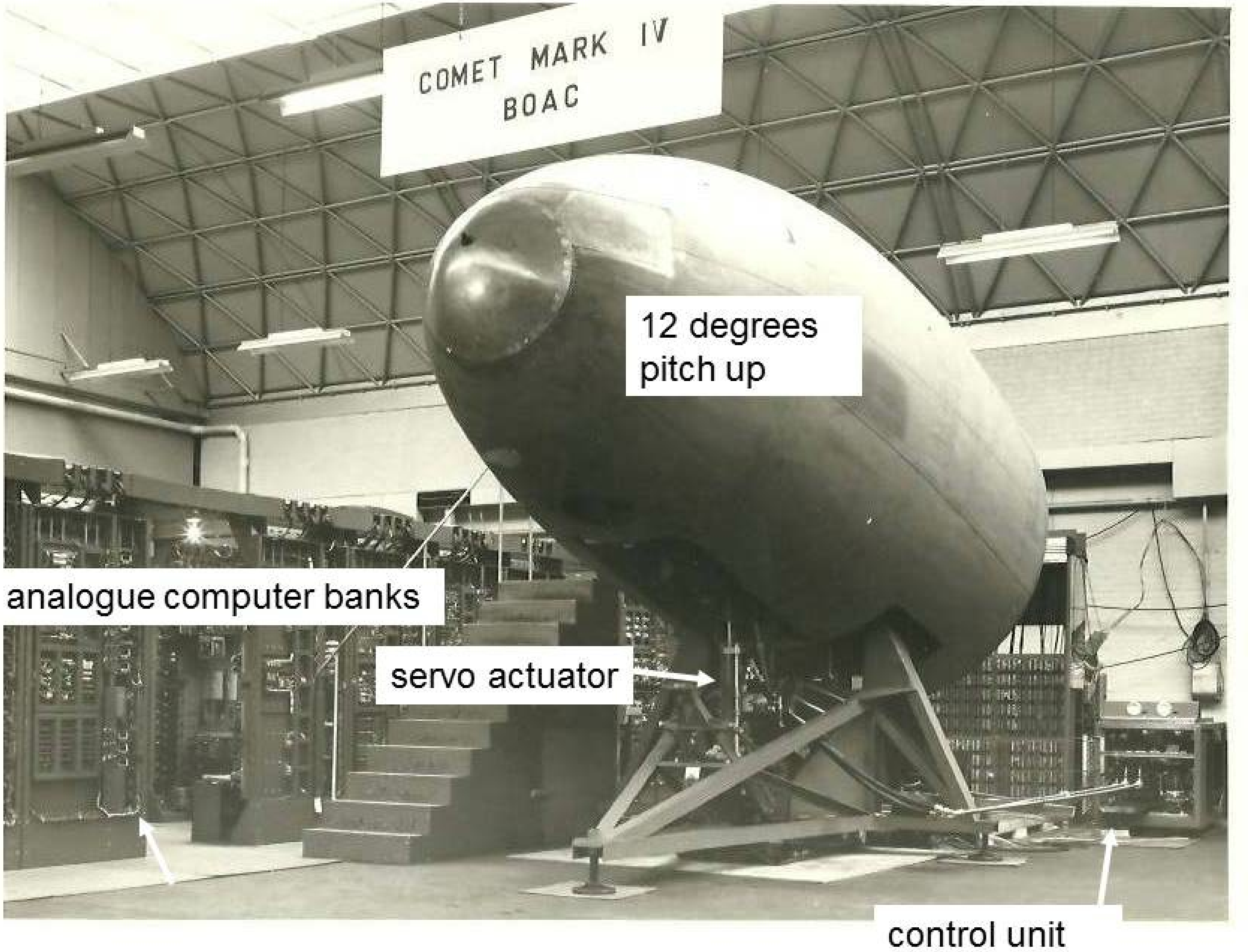

COMET MARK IV
BOAC
12 degrees
pitch up
analogue computer banks
servo actuator
control unit

FIG 3

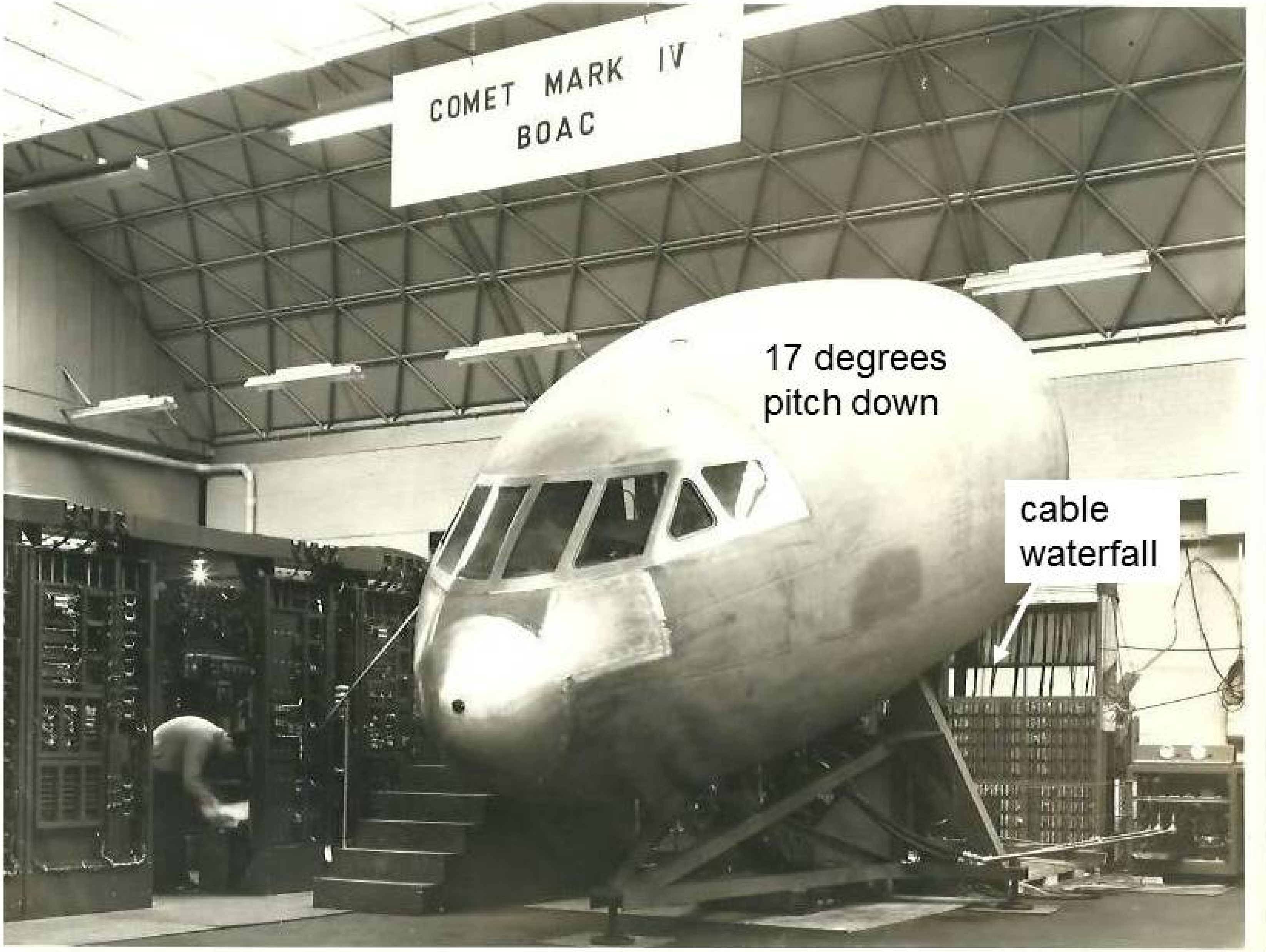


FIG 4

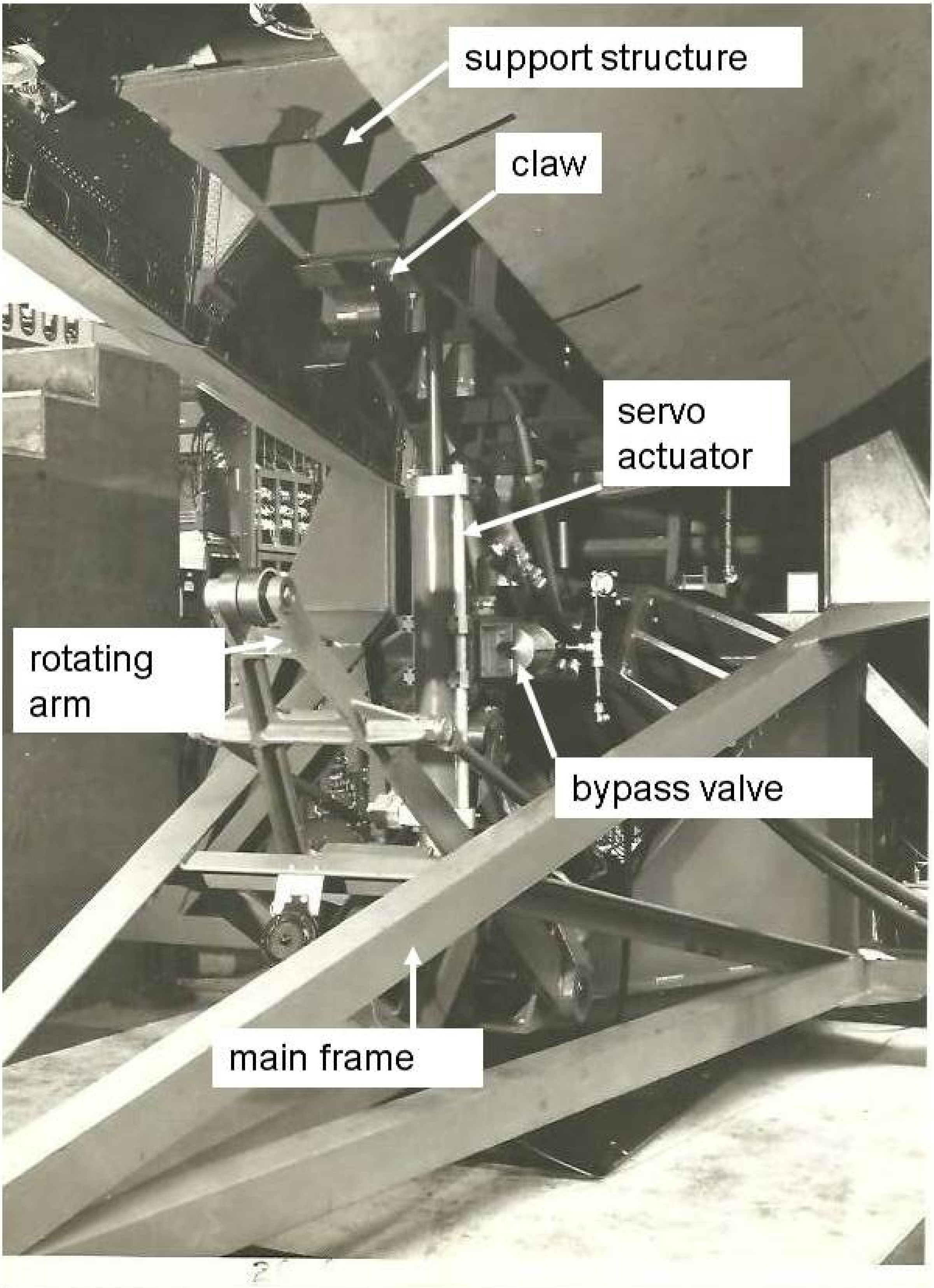
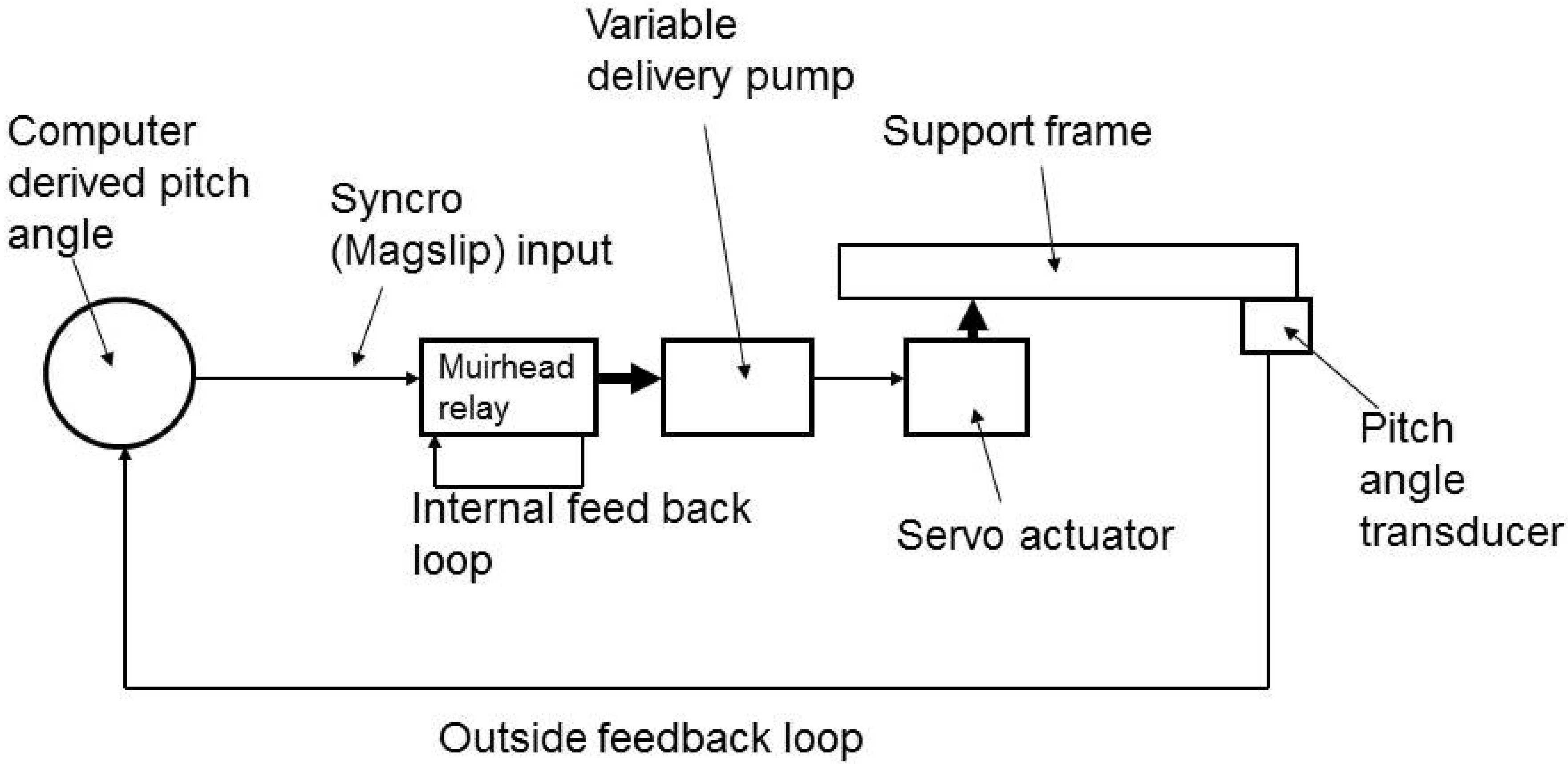

support structure
claw
servo
actuator
rotating
arm
bypass valve
main frame

FIG 5



Control loop schematic-motion system

FIG 6

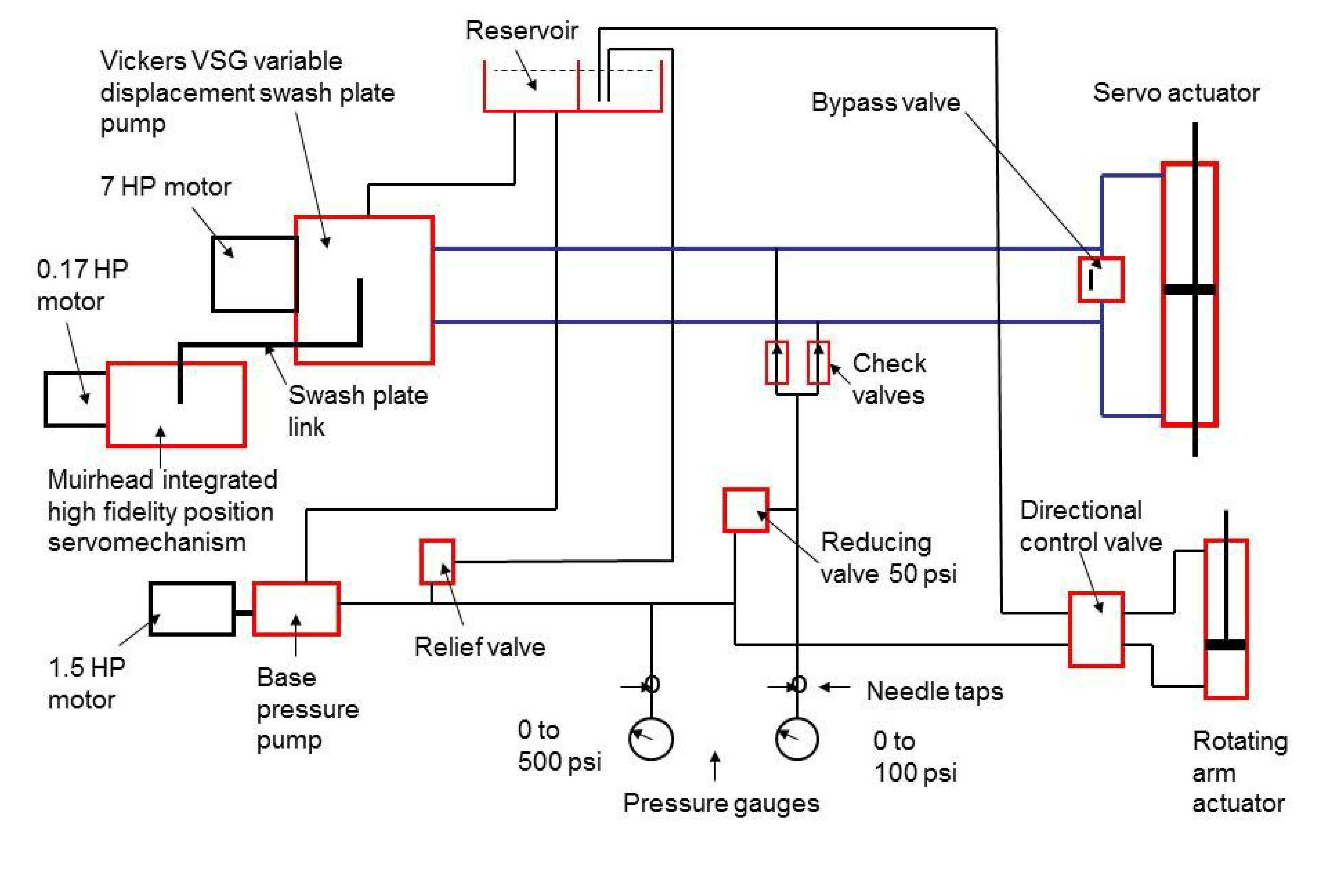


FIG 7

Hydraulic schematic- motion control system