F-104G STARFIGHTER

European Production of Systems BY MARK LAMBERT

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BY MARK LAMBERT

THE international F-104G production programme, the biggest ever undertaken, is nearing its peak and employing some 60,000 people in scores of factories in Germany, Belgium, Holland and Italy banded into a great European production consortium under the general direction of the NATO Starfighter Management Organization (NASMO) at Koblenz. Lockheed at Palmdale produced the initial aircraft, and early testing of the airframe and its complex equipment was carried out in the USA.

In due course the various European sources joined in the production process, gearing themselves in some cases to a type and complexity of production of which they had no previous experience. Problems arose, costs increased sharply and delays occurred—all of which provided excellent material for accusers, detractors and rivals, both political and commercial. Last year the criticism became sufficiently intense for NASMO to organize a tour of the major production factories to prove that the programme was indeed under way and producing results in terms of flyable aircraft. Shortly afterwards, NASMO followed up with a similar tour of inspection of some of the electronics companies.

"Flight International" for October 19, 1961, contained a description of the F-104G and an account of its manufacturing programme in three continents.

It must by now be apparent, even to the most ardent critics, that—even if all is not well—astonishing progress has been made. Several dozen European companies have been coaxed and chivvied through 15 years of technological progress in a matter of months. This is not to say that these companies were technologically years behind in their normal sphere of work, but hardly any of them had tackled production of this particular type.

It must also be noted that this feat could not have been achieved without the dynamic and generous support of the American designers, who evidently worked under a top-level directive to see that the programme did not collapse. Without the presence of senior American technical and administrative personnel, and underpinning by supplies direct from the USA, the programme would have run into dire trouble. No single European company would readily admit to us that it had been either incapable of

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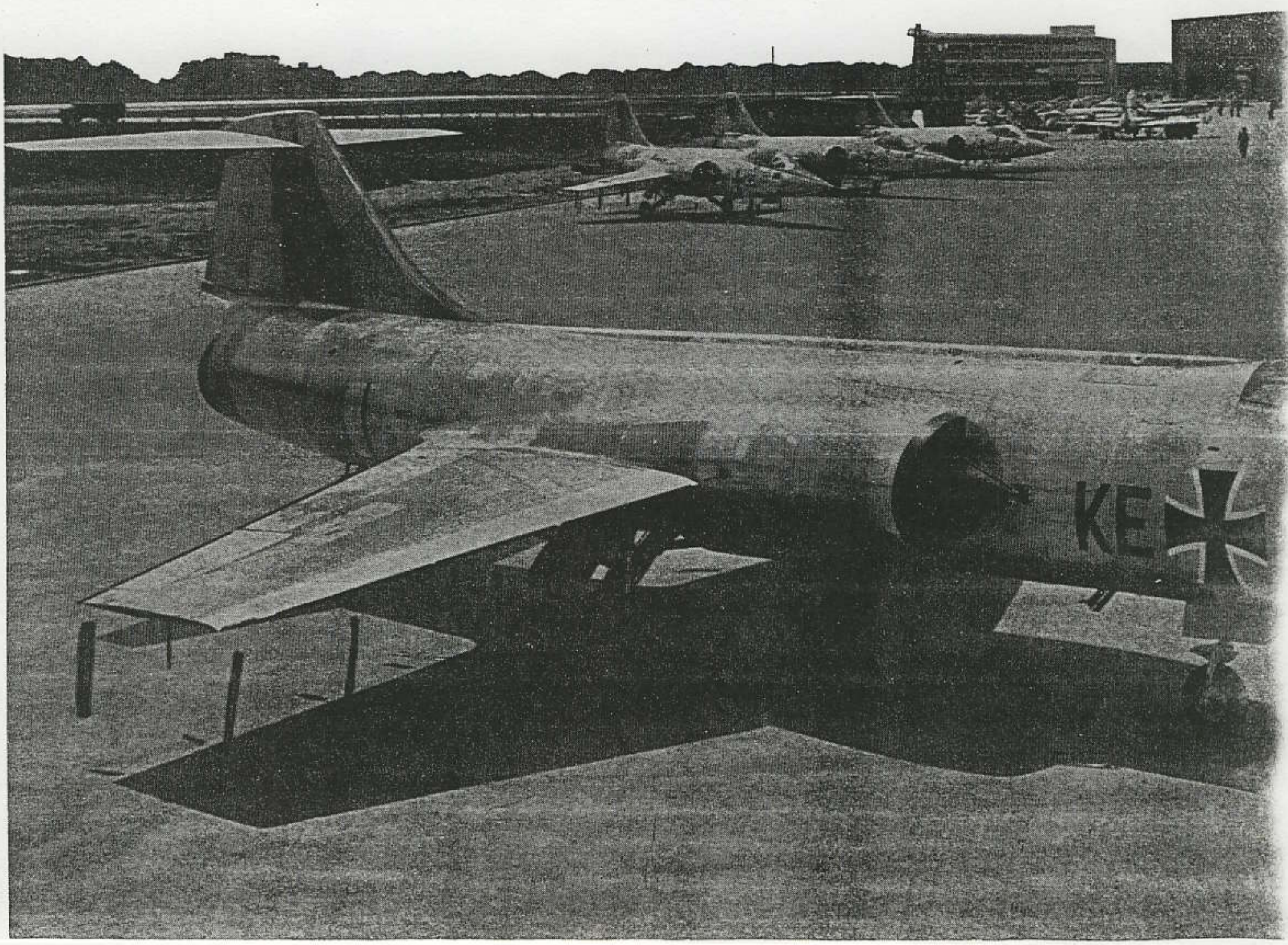
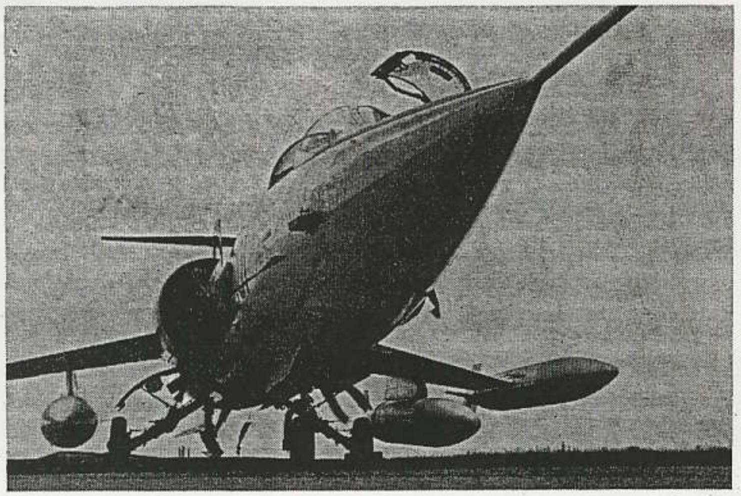
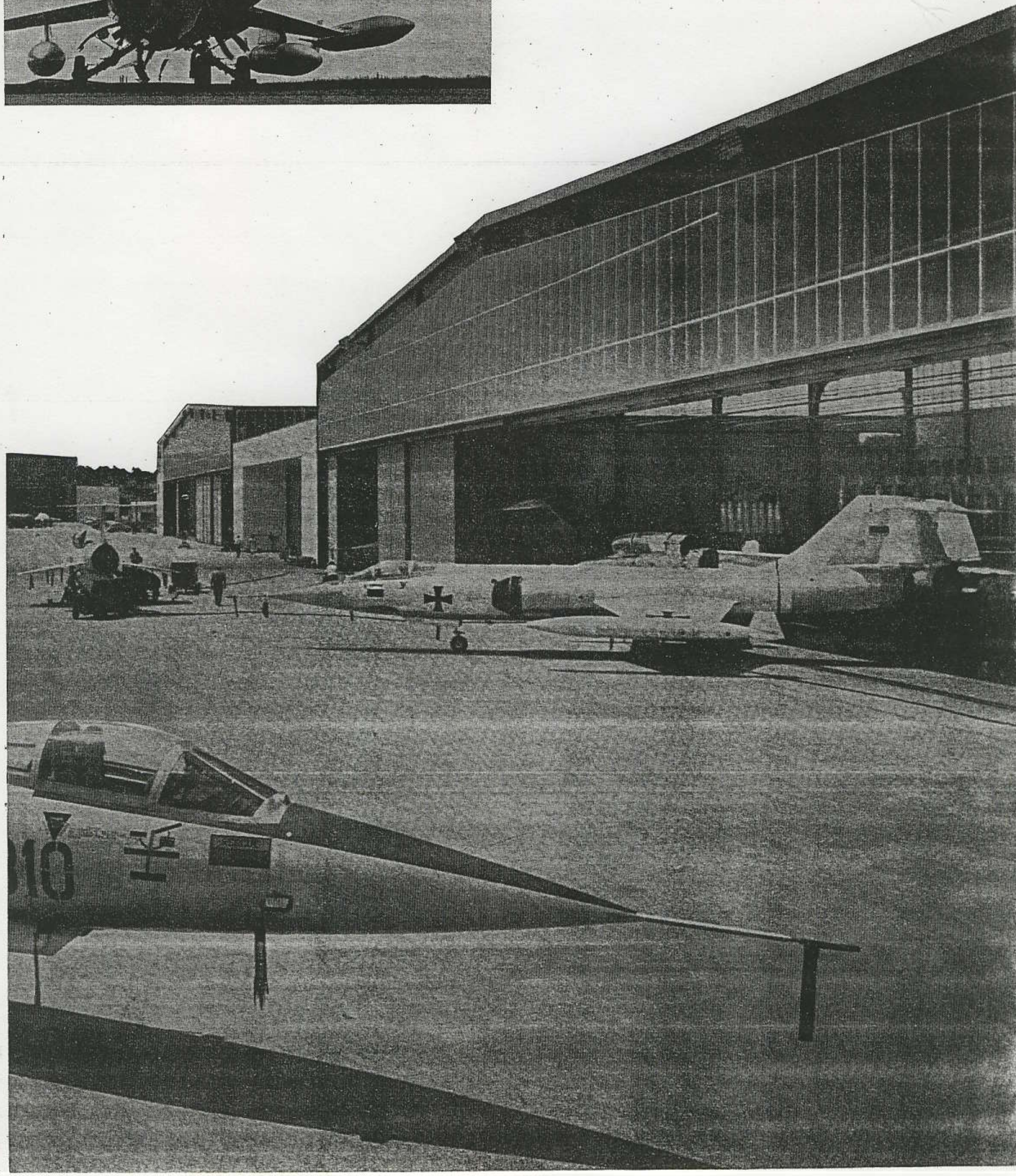


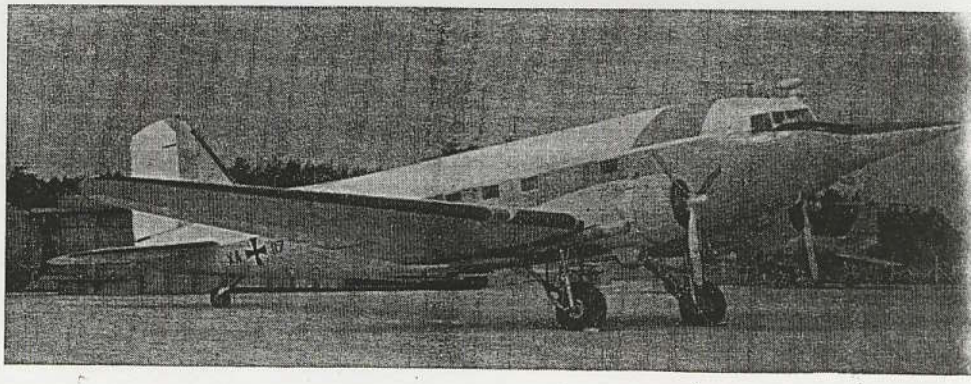


First of the European consortia to go into production with the F-104G was the Southern group. Completed aircraft are seen below emerging from the assembly hangars at the big new airfield at Manching, in Southern Germany. Left, the first Fokker-built F-104G fitted with its four external tanks



At Manching the first of several Dakotas being converted to carry Nasarr in the nose for initial training of pilots

"Flight International" photograph



undertaking the production work or of meeting the very close production schedules, but the fact remains that it did prove to be a major task for almost every one of them. In addition, there was the extra complication of production split between groups of companies in different parts of Europe, so that sub-assemblies made in different countries had to match exactly. This was fairly difficult to achieve in the airframe and engine sector, and was even more tricky in the field of electronics.

The general principle has been that two or three companies were designated as sources of a particular component or system. Each company would become sole source for one portion, but each would also carry out final assembly and testing of the whole, using parts supplied by its partners. At first, the European companies would receive complete equipment in crates, which they would assemble and test. Next they would receive "knock-down" systems, requiring a much more complete assembly operation. Then they would receive only individual components for full assembly, and after that they would begin to feed-in European-made basic components until the equipment was entirely indigenous.

A serious bottleneck in this process has been the supply of long-lead-time materials and components, because the potential suppliers were at first disinterested in the small quantities required for the original F-104G order for about 200 aircraft. It is still the case that electronic components are being supplied from the USA, but largely because European suppliers are not yet organized or approved to carry out the strict MIL quality-control procedures universally demanded by the US government and required also for the F-104G systems. Again, relatively small-batch production makes the work unwelcome.

The Starfighter programme is best viewed as a two-stage effort, in which the first stage is the establishment of the production capability. If this alone is successful, the effort will not have been wasted. The second stage is, of course, the effective utilization of the F-104G itself by the air forces of almost all of NATO—for Norway and Denmark are now to receive some as well as the four producer countries, and the Canadian-built CF-104s are to be based in Europe.

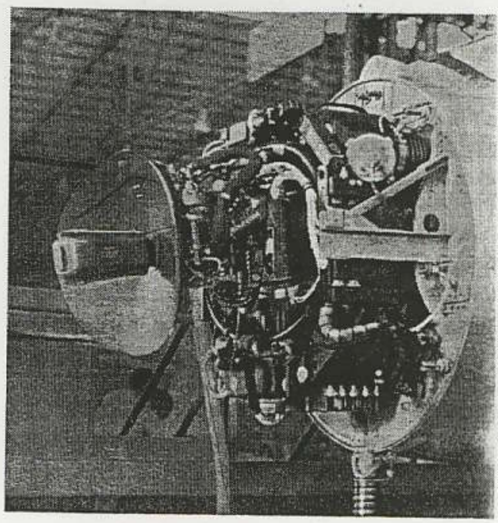
Despite some engineering change programmes (ECPs), the 104s are coming off the various production lines at an increasing rate. In fact, the whole process will start to run down again during 1964, and be virtually completed during 1965. Already the problems of a follow-on are looming, without much hope that a single project of anything like similar proportions will come to hand. Nevertheless, the industrial programme must be rated a success, and aircraft are coming off the lines faster than the air forces can accept them. Some 70 F-104Gs are standing at Manching, complete but awaiting acceptance by the Luftwaffe. The plans of the latter force for training pilots were outlined in *Flight International* for December 13 last year.

Pilot conversion training involves about 40hr of flying to learn the systems. For weapon training a further 30 or 40hr were needed and could be flown from Wheelus AFB, near Tripoli. An average pilot, returning to base at 500ft, could find the field within two passes, using his inertial position indication.

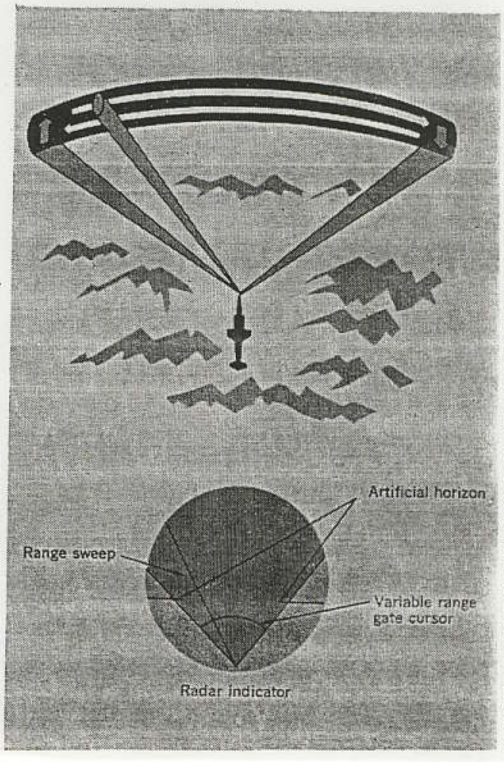
Much unfriendly propaganda has been spread to the effect that the F-104G is a dangerous and tactically useless aircraft. The only justification for this lies in the fact that, by its very nature, the F-104G must be a great deal less forgiving than the other aircraft at present in service in Europe. Col "Chuck" Yeager told *Flight International* some years ago that the F-104A was the pleasantest fighter he had flown, and other USAF pilots confirm this opinion in respect of the F-104C. German and Belgian test pilots also reported favourably on the handling of the much heavier G model; but they agreed with the company test pilot at Palmdale who said, "This is an absolutely straight airplane: it will not forgive you a single mistake you make."

Asked to elaborate on this statement, one test pilot in Germany mentioned pitch-up and loss of speed during the approach, when most of the cold thrust was being used to supply flap blowing as well as thrust. Drag would increase sharply as the speed reduced and the "back of the drag curve" was reached, but afterburner was available for an overshoot. Hot and high fields presented more of a problem in this respect. A tight circuit at military power could be made with 150lb of fuel. Squadron pilots did not normally train for dead-stick approaches; but such approaches could be made, and often had been. Estimates of the high and low key positions

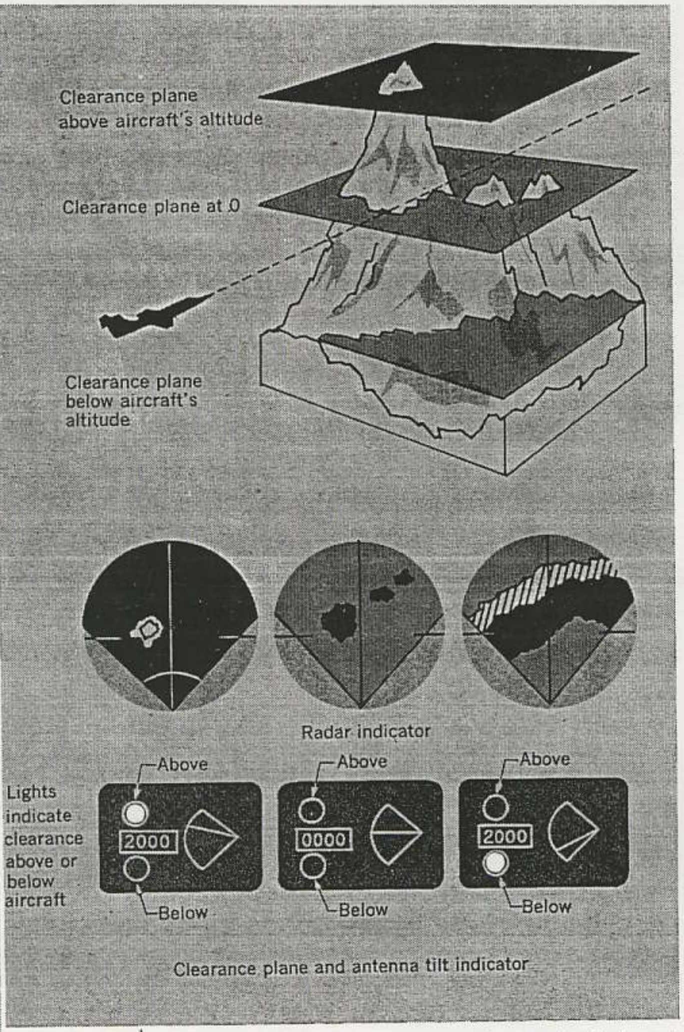
North American F-15A Nasarr navigation and attack radar installed in an F-104G on the Fiat assembly line at Turin Caselle



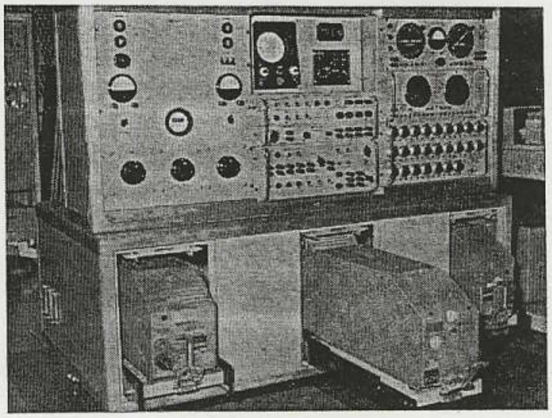
"Flight International" photograph



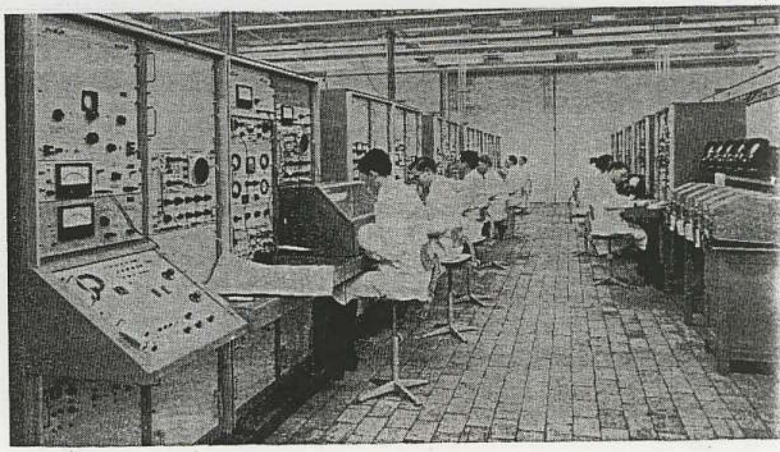
Interception search mode of Nasarr, showing also the horizon attitude line on the scope. When locked-on, Nasarr assumes a conical scan over a small area straight ahead. For other forms of attack, a range gate is swept along the fixed scan-line



Contour mapping mode of Nasarr, showing the horizontal clearance plane above, below and level with the aircraft



Three Nasarr "jeep cans" plugged into a test set made by Compagnie Belge d'Electronique et d'Automatisme (Cobelda)



Nasarr test bays in the MBLE factory at Brussels

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for such a manœuvre were 7,000ft and 4,000ft according to one pilot and 12,000ft-15,000ft and 7,000ft-8,000ft according to another. The dead-stick best glide speed was well over 300kt and the rate of descent up to 7,000ft/min. The flare-out had to be begun at about 1,500ft. This compares very favourably with Dyna-Soar, on which dead-stick landings will, of course, be routine.

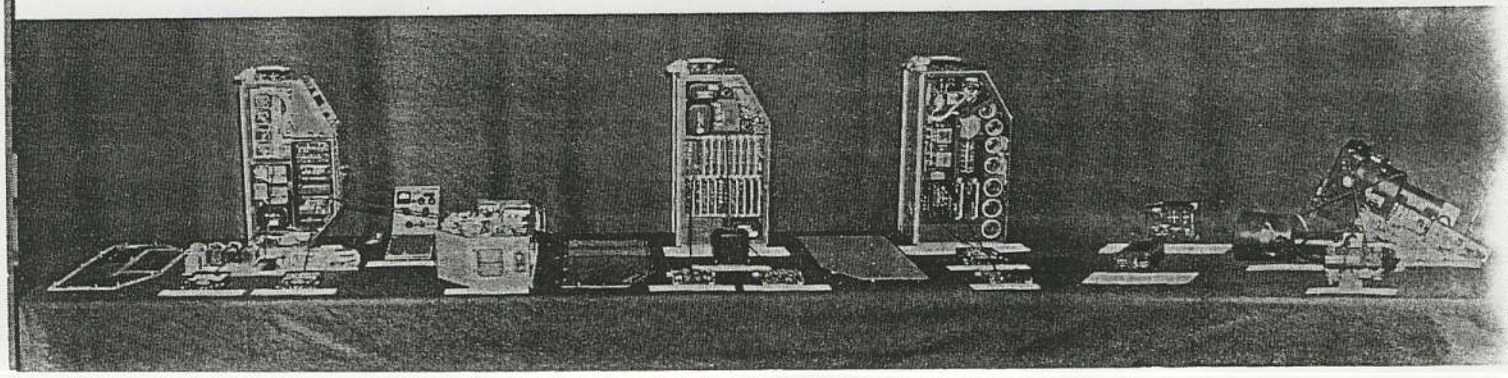
Power-limited ceiling—without zooming—for the F-104G was said to be 65,000ft. During one demonstration at Manching, an F-104G flew from Manching to the Bodensee and back, about 200 miles each way, making the outward flight at 40,000ft and mostly at Mach 1.8. The return was made in ten or 12 minutes at a speed of well over 1,000 m.p.h., the pilot reporting Mach numbers of around 1.4. German pilots claimed that with four external tanks they could fly at low level at 420kt for two hours with a fuel consumption of 4,300lb/hr. Range could be improved if the tanks were jettisoned when empty.

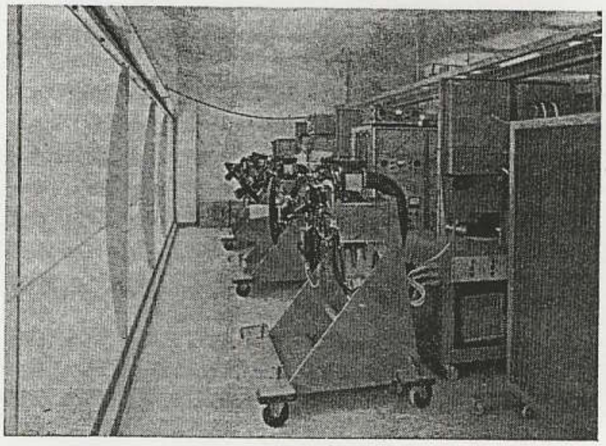
The Lockheed C-2 rocket ejection seat had proved excellent. Up to last August five successful ejections had been made, two of them at very low level.

During several demonstrations in Germany and Belgium, landing and take-off runs with normal external tankage appeared to be comparable to those of a Lightning, and certainly far better than indicated by the exceptional length of the runway at Manching. Pilots were quite happy to demonstrate the fairly limited aerobatics one expects of the majority of supersonic aircraft, but Bernard Neefs of Avions Fairey produced a spectacular show by any standards. One manœuvre was to make a normal approach and landing, and then apply full power and roll the aircraft at about 200ft during the overshoot, with the gear and take-off flap still extended. He said afterwards that a roll with high-lift devices extended could be "a tricky manœuvre."

Without its very extensive electronics the F-104G would have very limited value, as the USAF air defence squadrons apparently discovered. But with its inertial system, autopilot and radar it should become a potent weapon, and one which is not impossibly difficult to operate effectively. Certainly the German test pilots appear to have confidence in their ability to press home an attack hundreds of miles from base with relative immunity from ground defences.

Nasarr component breakdown, showingt the "jeep cans" at left, indicators in the centre and nose-mounted units at right





Three Nasarr aerials under test at North American Aviation SpA. They scan surrounding countryside through a dielectric wall

Starfighter Electronics

The F-104G has 12 electronic systems broadly divided between weapon control and communication-navigation-identification, the former being extensively integrated. Many systems are packaged in special containers, tailored to the electronics bay aft of the cockpit and generally called "Jeep cans" because of their resemblance to the famous 4 gal fuel container. A number of them have test connections for automatic checkout equipment. A further part of the programme is a very considerable amount of specialized test equipment for production and flight-line use. The task of "marrying" the airborne equipment to the airframe has been considerable, and each successive operator—Lockheed, the USAF Flight Test Center, the European manufacturers and the Luftwaffe—has had to go through a familiarization stage during which serviceability rates have been relatively poor. But once the know-how has been accumulated, and both pilots and maintenance staff have got to know the systems, the overall performance has been good. Some excellent mean times between failure and accuracies are achieved.

The weapon control systems are led by the Autonetics Nasarr monopulse radar for ground- and contour-mapping, terrain avoidance and airborne interception. Nasarr is the predominant system in the aircraft, and a key element in the attack role. To assist in radar lead-computing in pursuit-course air-to-air gunnery, steering reference and lock-on during missile launching, and for bombing, there are the optical and infra-red sights. In early F-104Gs, LABS delivery of the nuclear store, by way of several manœuvres, is controlled by the Mergenthaler Linotype M-2 bombing computer; but this equipment is now being replaced by the simpler and smaller Lear dual timer.

The communications-navigation-identification group consists mainly of the Litton Industries LN-3 inertial system, the Computing Devices of Canada Position and Homing Indicator IVB, AiResearch air-data computer and Honeywell MH-97G autopilot, all of which are to some extent integrated among themselves and with the weapon control systems. Finally there are the Canadian Collins AN/ARC-552 UHF radio, a three-channel UHF stand-by radio (as yet undecided), the I.T. & T. AN/ARN-52 Tacan and the Hazeltine AN/APX-46 IFF.

All this equipment is being progressively produced in Europe, as seen in the table on page 11. A typical sequence for licence production is that undertaken by MBLE for their portion of Nasarr. They received 24 sets of "black boxes," which they inspected and tested—itself a lengthy procedure taking several weeks for each set of equipment. They then received 85 "knock-down" sets, which they assembled and tested. Finally they are receiving 55 sets of detail components with which they will carry out the complete assembly operation. At the beginning of December they had delivered three Nasarrs and had another six ready.

Nasarr

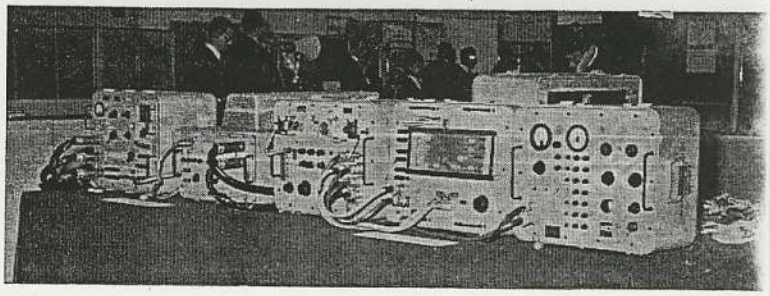
Eye of the F-104G is the North American Search and Ranging Radar (Nasarr), developed since 1957 by NAA's Autonetics division. It is also installed in the Republic F-105D, and is made by four main European licensees from whom Autonetics have received contracts for assemblies and parts worth $44m. About 400 sets have so far been delivered in component or subassembly form. Each Nasarr weighs 311lb, and costs approximately $100,000 (£36,000). The capabilities and operating modes were specified in November 1959, the primary requirement being for attack navigation and bombing, though an air-to-air interception capability was subsequently added. Nasarr, designated F-15A, has passed through -11, -21, -31, -32 and -41 stages, and now meets the reliability and performance specifications originally laid down. Existing -31 sets are being modified to -41, which represents the final configuration.

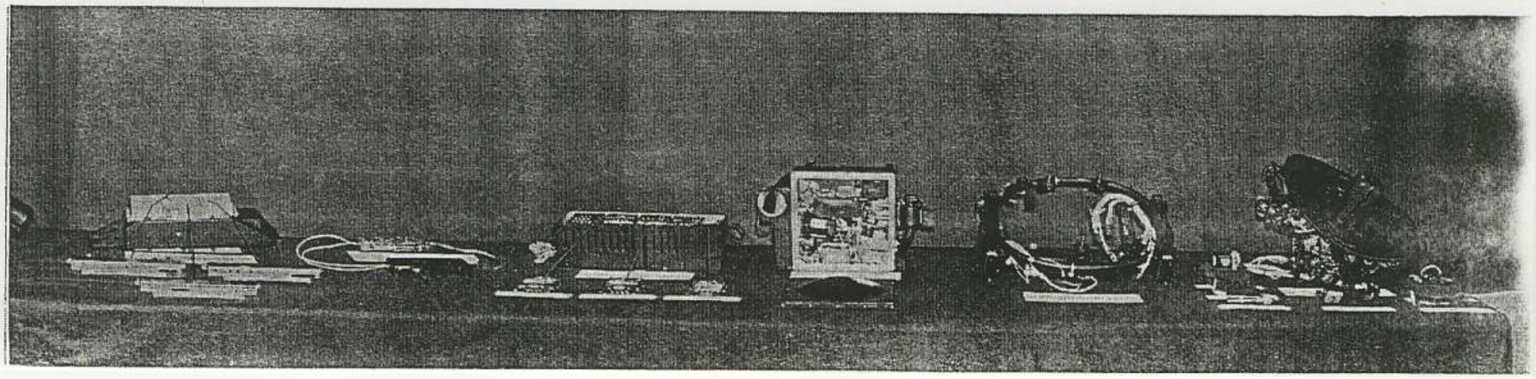
Autonetics established at its own expense a wholly owned subsidiary at Turin Caselle Airport called North American Aviation SpA, in order to co-ordinate and support all Nasarr work in Europe. Today NAA SpA provides training, maintenance and modification service, quality control and performance records, and maintains an extensive network of field-representatives. This is typical of the type of support being provided by all the major US companies involved, in their determination to see the programme through to a successful conclusion; and it is to a great extent by their efforts that the various deficiences and slippages of earlier days have been largely recouped.

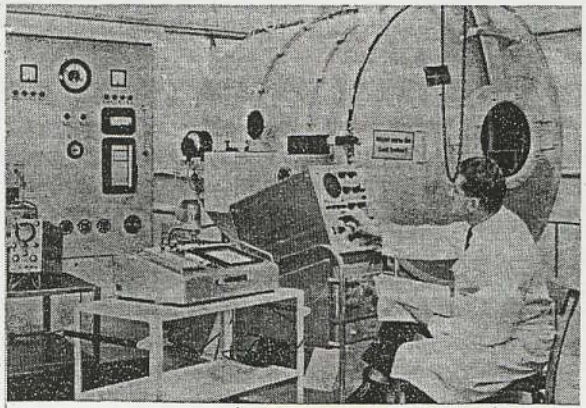
Nasarr is easily the largest single system in the F-104G, and it is in some ways its most intriguing feature. Although it has comprehensive facilities for the air-to-air use of gun, rocket and missile armament in either lead-pursuit or collision-course attacks, its most striking capability is in low-level navigation and terrain avoidance, and in locating and attacking surface targets. Really effective use of the radar calls for a high degree of pilot skill. His ability to read the radar picture and control the presentation while flying at sonic speed among mountains calls for careful training and pre-flight study. There is relatively little that he need do with the navigation systems, but the success of his approach to the target and attack depend largely upon his ability as a radar operator. It is for this reason that such emphasis has been laid in recent months on Nasarr training aircraft. Unfortunately, the crucial element in Nasarr operation is the time scale determined by the speed of the aircraft, and a trainer much slower than the operational machine has a correspondingly limited value.

In the air-to-air search mode, Nasarr scans over a fan-shaped arc ahead of the aircraft, the aerial shifting up or down at the end of each sweep to cover a forward sector of some depth. When a target is located, the pilot presses the action/reject button on the stick to make the aerial scan a narrow sector bracketing the target echo. He then moves a range gate on the scope over the target echo, and

Portable test equipment for line-checking of installed Nasarr







Left, environmental testing under low pressure, and humidity and shock, in the Telefunken factory at Ulm. Right, some of the extensive test bays in the NAA SpA factory at Turin. It is in such places that the real importance of the F-104G programme is apparent

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presses the action/reject button again to lock-on. The display then changes to a conventional cross-and-dot interception director pattern, surrounded by a range and rate-of-range ring. Armament is controlled according to the setting of the armament computer, and weapon release may be automatic. The usual break-away cross replaces the display when the weapons are fired or range becomes dangerously close. The search scan is yaw and pitch stabilized, and a horizon line remains in view to give an indication of aircraft attitude.

In visual conditions, the pilot can lock the scan on the aircraft datum-line and track the target through the visual weapon sight. Continuous ranging then controls weapon release according to the setting of the armament computer. Both these methods can also be used for shooting with the 20mm Vulcan "Gatling gun." The fixed-beam ranging mode can also be used, in conjunction with a bomb-ballistics computer, for blind or visual, normal or dive bombing. The pilot presses the "pickle button" at the appropriate range, and bomb-release is automatic.

The optical sight and in-range computer, infra-red sight—used in conjunction with infra-red homing missiles—and bombing computer are all integrated with the radar, and other signals are also obtained from the navigation and air-data systems. Early F-104Gs had the Mergenthaler Linotype M-2 bombing computer, and machines now coming off the lines have space provisions for it; but the Lear dual timer, a simpler and cheaper device with equivalent capabilities, is being substituted.

For navigation and target-identification purposes Nasarr provides four modes of operation. Normal ground-mapping for the purpose of identifying landmarks and making level bombing runs is achieved by simply deflecting the aerial downwards and scanning a sector of ground ahead at ranges varying between 80 and 20 miles. The view can also be modified to spoiled-beam (cosec^2) scan by moving a deflector plate in the aerial dish. The artificial horizon lines remain visible and a fixed azimuth line and controllable range marker are provided.

The third mode is contour-mapping, in which the radar scope displays only those topographical features which project through a chosen clearance plane. This plane is always parallel to the local horizontal, and its relative elevation can be adjusted at will between 6,000ft above and 6,000ft below the altitude of the aircraft. A small indicator panel shows the direction of aerial deflection and the relative height of the clearance plane, with lights indicating whether the plane is above or below the aircraft.

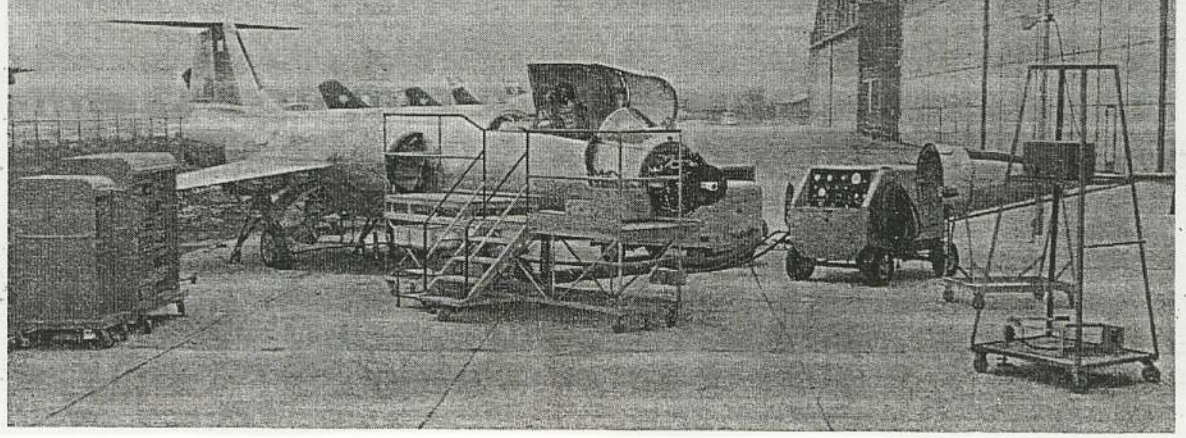
The final mode is terrain avoidance. In this case the radar again displays topographical features projecting through a given plane, but the surface of the plane remains parallel to the aircraft flight path. If the pilot sees an object projecting into his flight path, he can pull the nose of the aircraft up until the object disappears below the clearance plane, or he can fly round it. This mode greatly simplifies the task of flying close to ground in hilly country at night or in bad weather.

Nasarr is a monopulse radar operating in X-band and employing monopulse resolution-improvement circuits, which not only produce definition equivalent to that from a much larger aerial but also make the system less vulnerable to spurious signals and deliberate jamming. The synchronizer and transmitter are mounted in a single package, with the aerial in the nose of the aircraft behind a high-accuracy glass-fibre radome able to withstand rain and hail at 1,400 m.p.h. A high-brightness, direct-view display tube, antenna clearance-plane indicator and the pilot's controller are on the main cockpit instrument panel and port console. Three "Jeep cans" in the electronics compartment contain the low-voltage power supply, armament control computer and electronic control amplifier and calibration control.

The last-named provides a pre-flight check-out and setting-up facility for routine maintenance purposes. Testing on the ground requires the use of a cooling truck, to dissipate the 4,000W of heat generated by the equipment, as well as an electrical supply trolley and hydraulic-power truck. Some of this test equipment is intended mainly for second-line maintenance and production-line use, and portable test cases are available for a squadron flight-line. A full pre-flight check of Nasarr can be performed in from ten to 30min, depending upon the procedure employed and the skill of the operator.

This latter factor has proved crucial to F-104G readiness, particularly in the Luftwaffe where there is at present a shortage of skilled electronics personnel. The German authorities have also proved reluctant to accept outside technical help, and seem to have been making heavy weather of the initial learning period. The situation should improve when more automatic test and test-calibration equipment becomes available.

A Fiat-built Starfighter at Turin Caselle, surrounded by cooling and power trucks and electronics test equipment



LN-3 Inertial System

Litton Industries are one of the major producers of inertial systems in the USA, and have made a series of pure and hybrid systems for a number of American aircraft. The LN-1A was a precision attitude reference for the Grumman E-1A Tracer; the LN-2A, -2B and -2C are Doppler-inertial systems respectively for the A-6A Intruder, E-2A Hawkeye and P-3A Orion. The LN-3-2A is used in the F-104G system, and the LN-3-2B in the CF-104. The LN-4 is a miniature inertial system for a manned orbital vehicle, and the LN-5 is a "state of the art experimentation" astro-inertial system installed in an R4Y (Convair 340). The LN-7A is an astro-inertial-Doppler system for a classified application.

LN-3 systems have been in production in the USA since 1960, and are based on the P-200 platform, containing two two-axis gyros and three accelerometers, and weighing 30lb. Total system weight is 79.8lb and power consumption 520W. The identical gyros are floated in low-viscosity FS-5 fluorolube allowing operation and storage in temperatures as low as −67°F, and have a drift rate less than 0.01°/hr. They measure 3in diameter by 4in long and weigh 2lb each. Mounted on top of the platform container is the adapter unit housing the heading servo system and servo follow-ups providing multiple outputs of pitch, roll and heading angles.

Platform stabilization electronics, navigation Earth-reference computer and power supply are contained in a single "jeep can" in the electronics bay. The pilot has only an align-control panel, for setting initial position before take-off and a mode-selecter for warm-up, alignment, navigation or emergency compass-only modes. Portable test equipment provides for trimming of gyro drift and for general check-out, although a certain amount of self-test circuitry is incorporated in the basic equipment.

The LN-3 provides attitude information to the Nasarr radar, MH-97G autopilot and bombing computer as well as performing its basic navigation function. But the course and distance outputs used by the pilot for various target destinations are handled by the PHI (position and homing indicator). For the basic terrestrial calculations Litton employ a spherical co-ordinate system which places a "pseudo north pole" on the Earth's equator and establishes as the equator of a grid system an arbitrary reference meridian whose location is determined by the initial aircraft position co-ordinates set in the alignment control. In this way the system maintains accuracy at high Earth latitudes, while allowing operation at up to 1,000 miles from the base meridian.

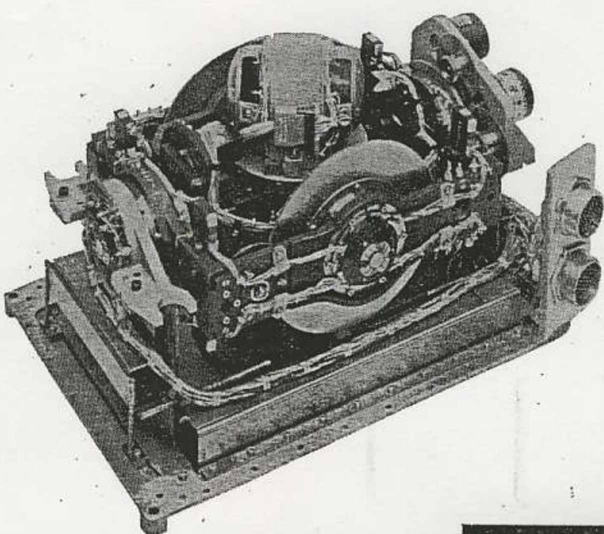
Before a flight, the platform is started up by first selecting the stand-by mode, during which the gyro fluid and precision resistors and capacitors warm-up to operating temperature. Rate of warm-up is 10°F/min, and the time required varies with the initial temperature of the equipment up to 15min. The cooling-down rate after switching off is only 10°F per hour, so that the equipment will reach operating temperature in 1.5min, 1.5hr after being switched off (3hr with a boost heating rate mentioned presently). After some warming-up the LN-3 is switched to the align mode, when the platform is approximately levelled in a few seconds and the gyros spun-up to operating speed for one minute. When the gyros take over control, the accelerometers are used to sense level attitude and the gyros torque the platform to the vertical. After about 70sec the platform begins the gyro-compassing mode during which the system is aligned with North, sensing the Earth's rotation. The alignment sequence is automatic after the pilot has made the initial selection, and takes between six and eight minutes, though it can be shortened at the expense of accuracy. Compass errors will also affect precision of alignment.

To overcome what might be a delay of 20min for inertial-system alignment before take-off, Litton have provided an "alert align" mode in which the alignment and warming-up process is completed well in advance, when the aircraft is parked. A synchro memorizes the correct platform heading, and the system can be started up and realigned in 90sec before a scramble take-off, so long as the aircraft is not moved after the initial alignment. "Alert align" does not significantly compromise accuracy.

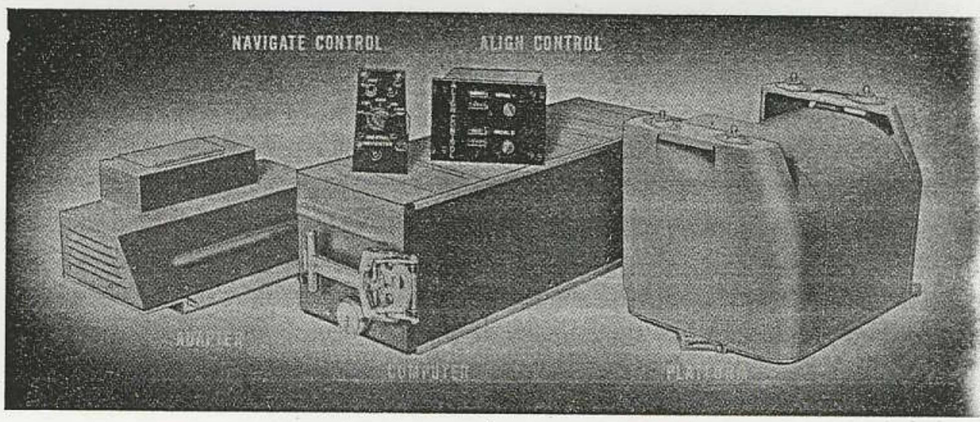
Alignment is, of course, much simpler on land than at sea. It is for instance necessary for a carrier to sail for 30min on a straight course while the ship's motion is averaged and heading derived for aligning an aircraft inertial system. To this end Litton are studying a master platform fitted in the ship, which would be kept running continuously for days at a time and from which the aircraft could acquire an alignment setting in some 30sec.

Periodic trimming of the LN-3 gyros has been necessary, but repeatability is of such a standard that the French government, testing a Litton platform in a Mystère at Brétigny, were able to operate for five weeks without trimming. They made altogether 53 sorties, each averaging 109min navigation, and ran one continuous 7hr test by keeping the system running through three flights.

Specified navigation accuracy for the LN-3 is a 50 per cent circular-error probability of two nautical miles after one hour's operation, which is equivalent to a 98 per cent c.e.p. of four nautical miles. Until the -9 version of the LN-3-2A came into service



Above, The P-200 platform of the Litton LN-3 inertial platform, containing two two-degree-of-freedom gyros



Components of the LN-3. The adapter is mounted on top of the platform case when installed in the aircraft

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results were outside these limits by a fair margin, but it has now been handsomely exceeded in a number of groups of flights. Each time the system has been operated by another unit or agency, the performance has had to be built up anew. This accounts for initial reports of poor performance in Europe, where the results at manufacturer level are now well within specification. The Luftwaffe at Nörvenich is gaining experience in operating the system.

Additional improvements now possible include a warm-up rate of 20°F/min and the use of air-bearing gyros offering random drift rates measured in thousandths, rather than hundredths, of a degree per hour. Air bearings can suffer severe wear during the starting and stopping phases, but Litton have already successfully run such a gyro through 85,000 stops and starts.

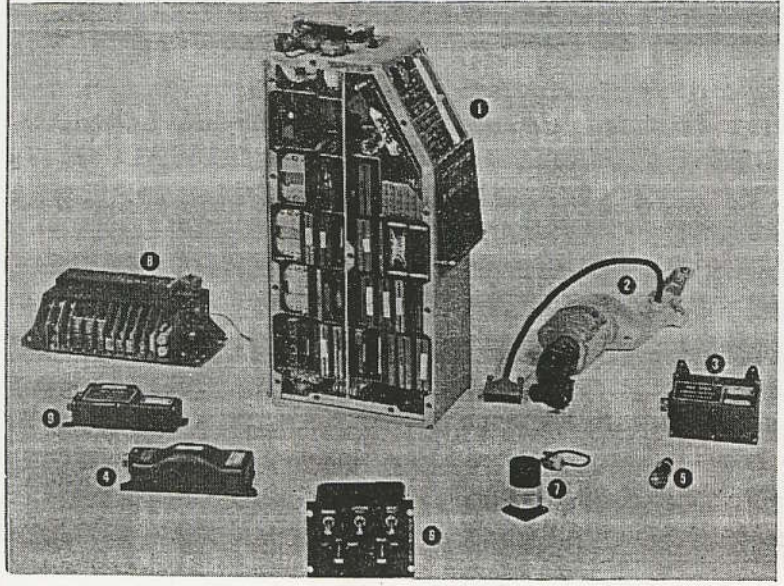
During manufacturer's development flying at Palmdale, some 1,167 flights were made up to October 1961, and the c.e.p. of the LN-3 and PHI combined was a mile or so outside specification. The PHI contribution is impossible to assess, but the manufacturer's specification states that accuracy is ± 1.4 n.m. plus 0.35 per cent of the total distance travelled. From October 1961 to January 1962 a further 123 flights at Palmdale were assessed, following incorporation of the -9 modifications, and the c.e.p. came almost up to specification. Initial test flights made at Edwards AFB with unmodified LN-3s showed somewhat poorer results. But further trials with modified systems, including a series of flights at low level with violent manœuvring, intended to investigate the use of inertial systems in the F-4C Phantom 2, gave accuracies well within specification.

Early F-104Gs assembled at Manching by Messerschmitt from US or Canadian parts showed a similar improvement in performance. During 17 flights from November 1961 to January 1962, the 50 per cent c.e.p. was relatively poor, but during a second series of 41 flights in April, achieved accuracies came well within specification. In August Fairey and Sabca at Gosselies were reporting performance almost as good.

Using the criterion of a "maintenance effort" representing about 5hr work, Edwards assessed the LN-3 as requiring 0.3 efforts per flight in the difficult "avionics marriage" period, when the equipment was being matched to the aircraft. After about 100 flights the figure flattened out to 0.02 efforts (0.1hr work) per flight, equivalent to 30 flights per effort or nine hours' flying per hour of maintenance.

At Edwards AFB, during Category 2 testing, and at Palmdale during the "avionics marriage" period, mean time between failures of pre-9 systems was considerably below the 200hr specified, but the target has been exceeded since then. Litton give an MTBF for verified LN-3 failures during Category 2 flight testing, equivalent to an "airborne navigation effectiveness"—i.e., successful sorties against sorties flown—approaching 95 per cent.

Whatever the apparent quality of this system, it provides a navigation capability unrivalled by that of any other tactical single-seater in Europe—with the possible exception of the F-105D. Pilots have reported very favourably upon it, pointing out that their knowledge of position after an hour's tactical flying is sufficiently good for them to be able to correct ground radar operators' position estimates. They claim it to be good enough for them to get within airborne-radar range of a ground target, thus allowing them to navigate a complete attack mission without any reliance on ground-based aids, or—even more important at high speeds—without the need for visual reference to the ground. The PHI allows the pilot to select by push-button immediate bearing and distance to any one of twelve different locations, including his home base. It is only with a system of this kind that the tactical use of the F-104G makes sense.



Components of the Honeywell MH-97G autopilot: 1, BG158 autopilot and damper computer; 2, control stick and grip; 3, roll-rate gyro package; 4, two-axis rate gyro package; 5, pitch trim indicator; 6, pilot's control panel; 7, normal accelerometer; 8, automatic pitch control computer; 9, APC gyro package

MH-97G Autopilot

Originally designed by Minneapolis-Honeywell for the F-104C, the MH-97G forms a comprehensive flight control system for the F-104G, containing a number of rate gyros of its own, but otherwise relying on the Litton LN-3, PHI and air-data computer for, respectively, attitude and heading information, navigation reference and height and Mach data. Honewell defensively claim that, because the pilot's most direct contact with the aircraft is through the autopilot, he attributes to this system many faults which actually originate in the more remote systems supporting it. In fact, the company is able to show some remarkably good MTBF figures for considerable portions of the MH-97G.

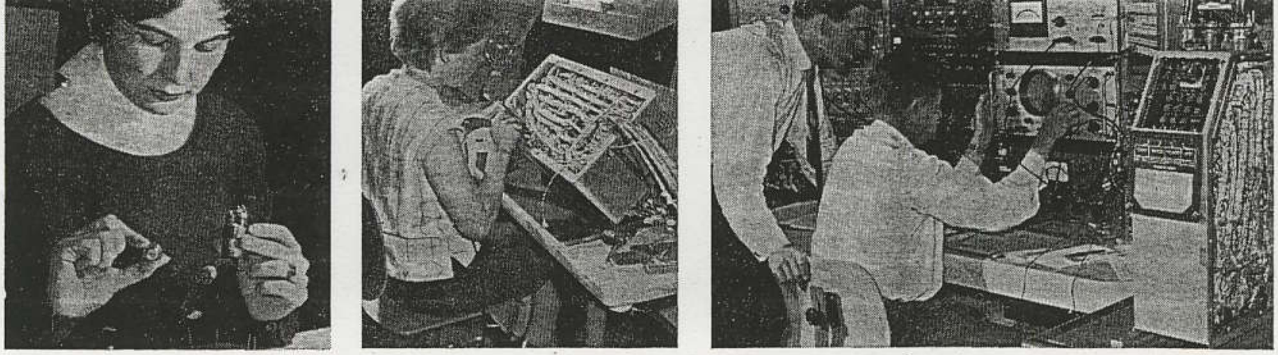
It provides three main sectors of flight control: autostabilizer three-axis damping; automatic pitch control (APC), which governs stall protection by stick shaking and then snatching; and flight-path control. Autostabilizer and APC normally remain engaged at all times, but the pilot can switch on the automatic flight-control system (AFCS) and the aircraft will be held in the attitude at the moment of engagement. Through a force-senser in the control column he can then set the aircraft in any attitude, under autopilot control; this is termed control-stick steering (CSS). If the bank angle at the moment of stick release is less than 7° the wings will be levelled and the existing heading held.

Roll and pitch channels can then be separately slaved to the various holds by switches on the control panel. For example, a standard turn can be demanded, but pitch will remain under CSS. Height or Mach hold can be engaged, leaving heading under CSS. By setting the inertial navigator and selecting PHI setting, the aircraft can be flown under heading-coupling to a PHI-defined, inertially located destination; and either height, Mach or CSS pitch holds can be used at the same time. Navigation information can also be derived from Tacan and PHI.

Numerous interlocks avoid superimposition of conflicting modes and allow for failures. The autopilot disengages if the APC or any stabilizer axis becomes disengaged, or if the monitors detect a fault. It will also revert to full CSS if more than 7lb stick force is applied to a coupled axis. Bank angle in the standard turn mode is adjusted between 15° and 48° according to airspeed. The AFCS reverts to CSS if pitch or bank exceed 66° during coupled flight. The autopilot will not engage if the gear or landing flaps are extended, but it can be functionally checked on the ground, with the engine running, by the pilot and crew chief performing and checking certain actions, such as deflecting the angle-of-attack vanes and undercarriage-door microswitches. An auto-trim system ensures that no out-of-trim forces occur on autopilot disengagement.

Angle of attack is one of the basic outputs of the air-data system, and the F-104G is notorious for requiring artificial stall protection. When the stalling angle is approached the APC stick-shaker operates. If the pilot continues to demand a nose-up attitude, a thruster applies a force of about 40lb to push the stick forward and disengages any autopilot modes then in force. The APC is automatically engaged at all times, except when gear and flaps are down, and will operate on the ground if the angle-of-attack sensing vanes are appropriately displaced.

The MH-97G will maintain pitch and roll attitude to within one degree, height to within 50ft or 0.2 per cent of indicated pressure altitude, and Mach number to within 0.02. All these features are necessary for effective use of the F-104G, especially during high-speed operation close to the ground or where maximum range is required. In the last-named case, for example, it is considered necessary to use the Mach-hold during the climb. CSS allows the pilot to devote minimum attention to actual attitude



Left to right: the Honeywell Golden Gnat miniature rate gyro and its rotor; wiring up the BG-158 computer in its "jeep can"; and testing the autopilot

control when his mind and hands may be considerably occupied by navigation and attack functions.

While attitude information is taken from the LN-3, the MH-97G has its own rate gyros, mounted in the APC system, in the roll rate and two-axis rate-gyro packages. In all cases the rate gyro used is the Honeywell Golden Gnat, a floated, single-axis unit weighing only 160gm and having a hysteresis rotor turning at 24,000 r.p.m. It can sense angular velocities from 0.01°/sec to 50°/sec. Super-clean rooms are used for assembly, and specially close quality-control is applied throughout the manufacturing process. Damper and autopilot computer circuitry, designated BG-158, is contained in a standard "jeep can." There are only 22 relays, solid-state switching being otherwise employed; and some electronic circuits are potted modules built up from three-dimensional clusters of components in which the leads from the components themselves are welded to form the interconnections.

Very extensive and specialized test equipment is used, here as elsewhere, to calibrate and check the autopilot before delivery. In addition, Honeywell have installed a sizeable analogue computer and control simulator at Dörligheim and are studying flight instrumentation and handling of typical VTOL aircraft, with a view to developing instrumentation for transition and landing. They supplied the stabilizer system for the German pre-VJ-101 VTOL "bedstead."

As already intimated, Honeywell are anxious to point out that, during 1,170 flights in Germany in the first ten months of 1962, 390 autopilot failures were claimed by pilots, but that only 21 of these (5.4 per cent) were actually the fault of the autopilot itself. The other 369 were traced to one of the other systems. During 42,000hr of user operations in the USA and Europe the BG-158 computer has shown an MTBF of 368hr, equal to 141 per cent of the reliability specification. The three-axis damper has achieved 3,062hr against the specified 690hr, and the APC 2,043hr, which is no less than 252 per cent of that required. Late last year there had never been a failure in the normal accelerometer unit or APC gyro package.

UG-1000 Check-out

Honeywell in Germany are also responsible for testing and delivering, though not for manufacturing, the UG-1000 automatic check-out trolley, about 70 of which have been ordered for the four original air forces in the F-104G programme. This set is one of the series of Automatic System Analysers made by Honeywell and described in *Flight International* for October 18.* It is designed to check the MH-97G in about four hours; without the UG-1000 this operation would take two days. The UG-1000 can also perform a rapid functional check in ten minutes. A2 and A3 models are being delivered now, but Honeywell are completing the design of the UG-1000G, which will be able to check not only the MH-97G but the LN-3, PHI-IVB, air-data computer and other systems.

—and, in greater detail, in our associated journal "Measurement and Control" for February 1962.

F-104G ELECTRONICS PRODUCTION

System	Designer	European Source	Remarks
Radar fire-control Nasarr	NAA Autonetics, Downey, California	North American Aviation SpA, *Turin*	overall support, training, modifications.
		Manufacture Belge de Lampes et de Matériel Electronique (MBLE),* *Brussels*	indicator, low-voltage power supply, electronic control amplifier: sub-contract from HSA for computer.
		Ateliers de Constructions Electriques de Charleroi (ACEC), *Belgium*	sub-contract from MBLE.
		Hollandse Signaalapparaten* (HSA), *Hengelo*	aerial assembly and computer.
		Telefunken, *Ulm**	synchronizer, receiver.
		Fabbrica Italiana Apparecchi Radio* (FIAR), *Italy*	transmitter, waveguide coupler, radar set control, clearance-plane indicator.
		Cobelda, *Belgium*	test and check-out.
Inertial system LN-3	Litton Industries, Beverly Hills, California	Litton Industries GmbH, *Hamburg*	overall co-ordination and liaison.
		C. Plath, *Hamburg**	manufacture and final assembly.
		Standard Elektrik Lorenz (SEL), *Germany*	navigation computer.
		Bell Telephone Manufacturing Co, *Belgium*	navigation computer.
		Fritz Hellige & Co, *Freiburg*	inertial gyros.
		Litton Italia, *Rome*	sub-contract.
Position and homing indicator IV B	Computing Devices o fCanada, Toronto	Teldix, *Heidelberg**	Telefunken/Bendix joint company.
		Ottico Meccanica Italiana (OMI), *Italy*	
Autopilot MH-97G	Minneapolis-Honeywell	Honeywell GmbH, *Frankfurt-Dorligheim**	manufacture; also UG-1000 check-out system.
		Officine Toscane Elettromeccaniche (OTE). *Florence*	sub-contract parts of APC and BG-158.
Optical sight and in-range computer	General Electric	OIP, *Belgium*	
		Allgemeine Elektrizitäts Gesellschaft (AEG), *Germany*	
nfra-red sight	Lockheed Aircraft (Lockheed-California Co), Burbank, Cal	Eltro, *Germany*	
		Optische Industrie de Oude-Delft, *Holland*	
Bombing computer M-2	Mergenthaler Linotype	Hollandse Signaalapparaten (HSA)	
Dual timer	Lear		
Air-data computer	AiResearch Divn, Garrett Corp	Interaero, *Germany*	subsidiary of Garrett Corp.
		Microtecnica, *Turin*	also makes J57 engine accessories.
UHF radio AN/ARC-552	Collins Radio of Canada	van der Heem, *Holland*	
UHF 3-channel emergency radio	RCA	three companies: not yet decided	
Tacan AN/ARN-52	I.T. & T.	Standard Elektrik Lorenz, *Germany*	
IFF AN/APX-46	Hazeltine	Siemens & Halske, *Germany*	
	Packard Bell		
	Stewart Warner		

* Final assembly, test and delivery of complete systems, as well as manufacture of certain portions of system.