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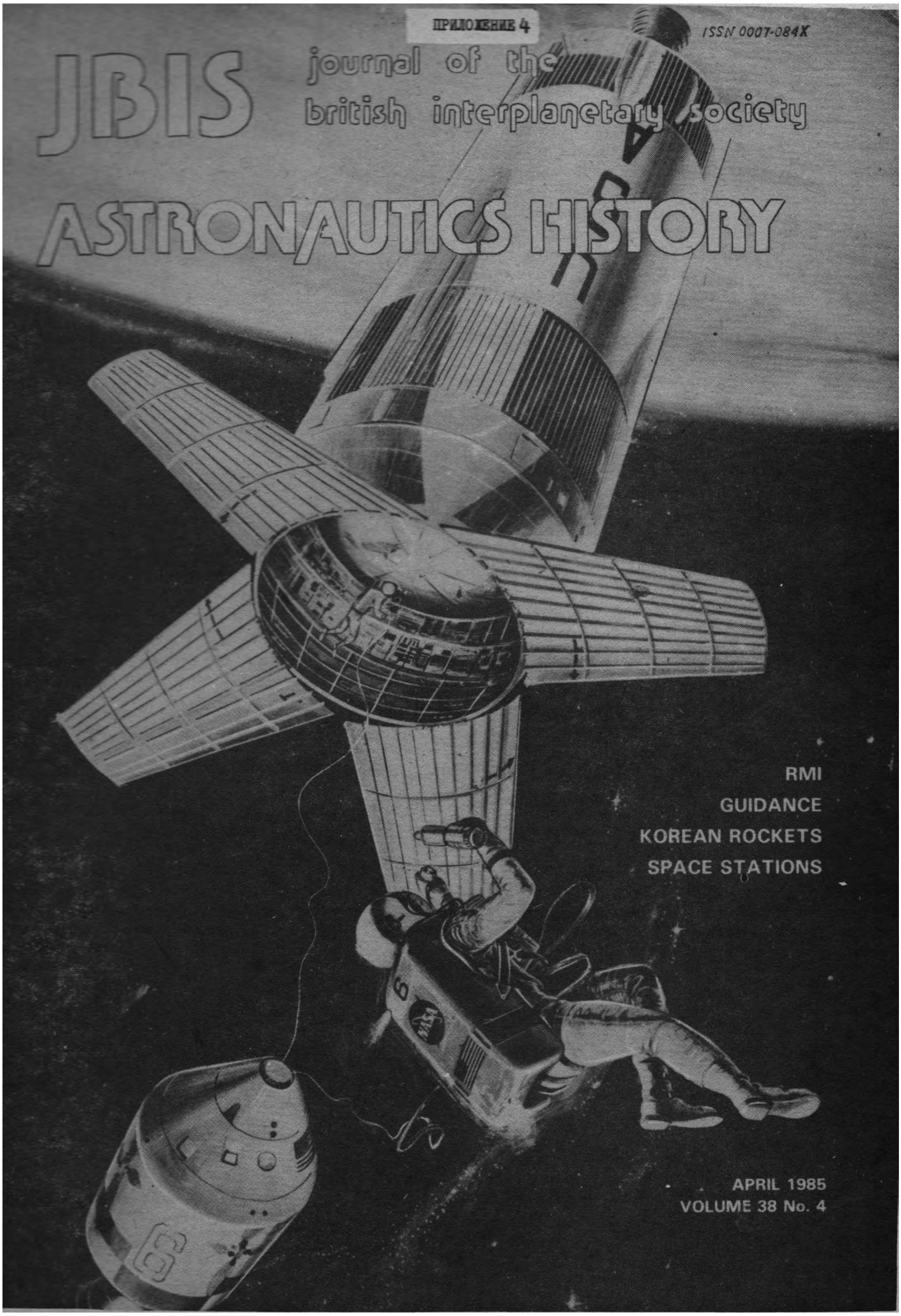
ASTRONAUTICS HISTORY

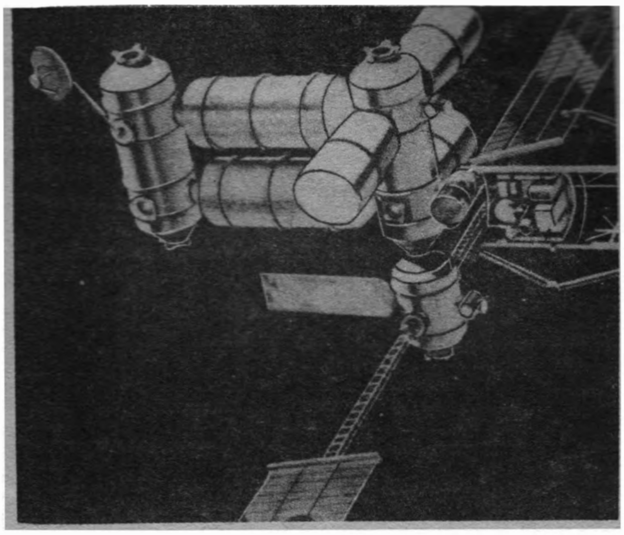


RMI
GUIDANCE
KOREAN ROCKETS
SPACE STATIONS

APRIL 1985
VOLUME 38 No. 4

SPACE STATION PLANS

The US Space Station is the next major manned space project of the western world, with initial operations in orbit expected in the early 1990's. Plans for participation are being considered by most European countries, including the UK. Our Society, which has long advocated permanent manned bases in space, will contribute further to the discussions by providing updated reviews at a one-day symposium. The date is 17 April 1985, the venue HQ. A provisional list of papers to be presented by a panel of international speakers will include the following:



1. **'European Space Station Overview,' by F. Longhurst (ESA).**
2. **'Space Station Platform - Overview,' by Dr. R.C. Parkinson (BAe).**
3. **'User Requirements for Space Stations,' by I. Franklin (BAe).**
4. **'Space Station Pressure Compartment,' by Prof. Valleriani (Aeritalia).**
5. **'Application of Propulsion Modules to Space Station Infrastructure,' by D. Gilmour (BAe).**
6. **'Orbital Replacement Units for Space Stations,' (Provisional).**
7. **'Assembly and Maintenance of Space Stations,' (Provisional).**
8. **'European Overview of the Space Station Proposals,' by R. Gibson.**

The Symposium will be held in the Society's Conference Room, 27/29 South Lambeth Road, London SW8 1SZ, England on 17 April, 9.30 a.m. to 5.30 p.m. The registration fee is £15 (non-members £17). Forms are now available from the Executive Secretary at the above address. The places remaining are limited so early application is advised.

1985 SUBSCRIPTION FEES

There is good news for all members: fees for 1985 will remain unchanged from 1984 in spite of rising costs.

Direct Debit Scheme

Our old Bankers Order system has been phased out. Direct Debit slips are now available from the Executive Secretary but, since they will not come into operation until 1986, a separate remittance for 1985 will have to be made.

Amounts payable for the calendar year January-December 1985 are as follows:

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Under the age of 18 years	£16.00	$26.00
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A reduction of £4.00 ($6.00) is allowed to members of every grade over the age of 65 years on 1 January 1985.

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ASTRONAUTICS HISTORY

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COVER

A Douglas Aircraft Company concept for orbital work to convert a Saturn 5 third stage into a space station. W. David Compton, in the first paper in this issue, discusses such proposals in 'The Rocket as Spacecraft: Spent Stages in Manned Space Flight.'

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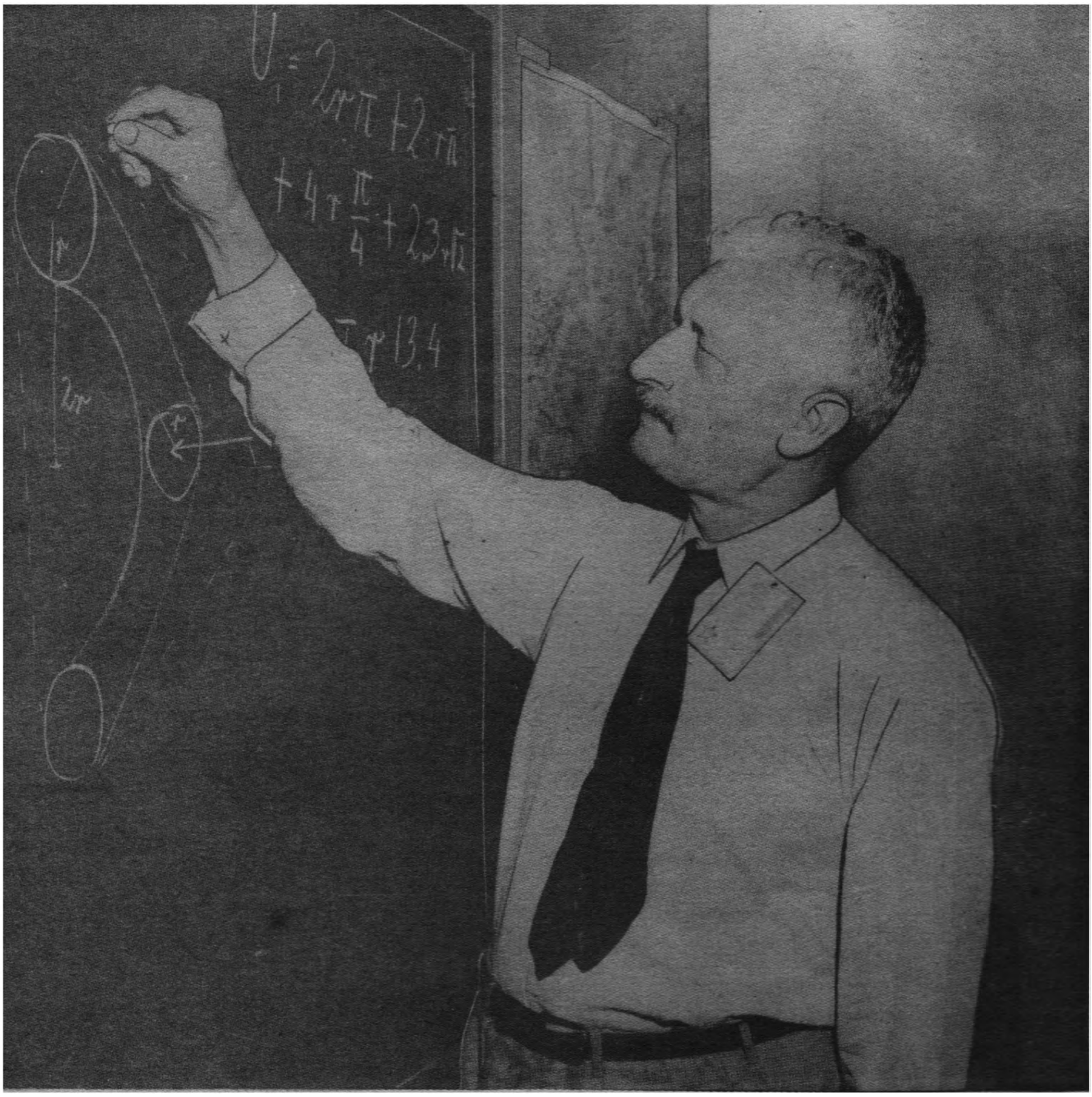

25 June 1984 marked the 90th birthday of astronautics pioneer Hermann Oberth. While often thought of as a German, he is actually a Hungarian since his birthplace (Sibiu) was then in the Austro-Hungarian empire. He did come from German stock, and when he was ready to enter the university his father sent him to Munich to matriculate in medicine. However, he concentrated more on the mathematics and astronomy, having read the novels of Jules Verne and Kurt Lasswitz.

In 1923, his book *Rakete zu den Plaanetenraeumen,* was published in which he outlined the fundamentals of interplanetary flight. The work became pivitol in influencing later scientists and engineers who ould design and construct the rockets that would prove his theories. For a few years, in the 1950's, he worked in Huntsville, Alabama, USA. There he was associated with Wernher von Braun, who as a teenager had been fascinated by Oberth's book. Oberth returned to Germany and currently lives in Feucht, Federal Republic of Germany.

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THE ROCKET AS SPACECRAFT: SPENT STAGES IN MANNED SPACE FLIGHT*

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Historian, Houston, Texas, USA.

The conversion of a spent propulsive stage of a launch vehicle into habitable living quarters for a crew in Earth orbit is an old idea, often discussed but never yet attempted. For almost four years, until an alternative became too attractive to ignore any longer, a spent-stage laboratory was the basis for planning NASA's first post-Apollo programme, which eventually became Skylab. This paper traces the history of the spent-stage concept and some of the difficulties encountered in attempting to put it into practice.

1. A HOME IN SPACE: LONDON, 1960

Londoners who crowded Kensington's Olympia exhibition centre in March 1960 for the annual Ideal Home Exhibition were given a glimpse of the future in the show's featured exhibit. A full year before any man had gone into space, the London *Daily Mail*, which sponsors the exhibition, had chosen 'A Home in Space' as the theme for the 1960 show. Towering some 18 m above the floor in the Empire Hall was a full-sized mockup of just such a home: a spacecraft that could accommodate four men for a month in Earth orbit (Fig. 1). The unique feature of this spacecraft was that it was actually the empty second stage of the rocket that had put the crew into orbit, emptied of its residual fuel and fitted out with equipment and supplies after it reached orbit. Its purpose was to conduct astronomical and other scientific observations above the atmosphere [1].

England was rocket- and space-conscious that spring, for the first US intermediate-range ballistic missile (Thor) squadrons were moving into their bases in East Anglia [2]. Indeed, the Ideal Home Show exhibit was distantly related to this event, for it was designed by the same company that built the Thor: the Douglas Aircraft Company of Santa Monica, California. A small group of engineers in Douglas's Advanced Design Section had conceived the spent-stage laboratory and drawn up the plans for the exhibit on a budget of $10,000 [3].

Home Show officials estimated that a million visitors saw the exhibit and that 150,000 of them climbed the stairways that led through it [4]. After the show was over, however, the exhibit was quickly forgotten in California; Douglas had just won the competition to build the S-IV second stage of NASA's Saturn I launch vehicle, which would be a pathfinder on the way to the Moon [5].

2. EARLIER SPENT-STAGE CONCEPTS

The idea of using an empty rocket stage as a manned spacecraft was first embodied in the Home Show exhibit. It appears to have been first documented a year earlier, in a study called 'Project Horizon,' a plan to establish and maintain an armed outpost on the Moon, conducted for the US Army by Wernher von Braun and a group at the Army Ballistic Missile Agency [6]. Von Braun later recalled that the spent-stage idea was one of many that his group had discussed informally at Peenemuende while working on the V2 project [7].

In postulating the use of such a makeshift, von Braun was looking for an expedient way to carry out Earth-orbital operations, which at the time were regarded as the indispensable first step in flights to the Moon and the planets [8]. A permanent space station in Earth orbit was considered the ideal base for orbital operations; Project Horizon assumed that by 1965 the United States would have established such a station (it was, in fact, on NASA's list of future space objectives). Lacking that, however, Horizon's authors suggested that a spent rocket stage could be converted into rudimentary quarters for the crews that assembled, fuelled and launched the Moon-bound spacecraft. Several such stages could be bundled together to build a semi-permanent station; and one sketch in the report showed 22 spent stages assembled into a wheel-shaped station similar to many that had been proposed before [9].

Nothing came of Project Horizon – the Army's last bid to participate in manned space flight – but the spent-stage idea survived, latent, to be revived later. The Earth-orbiting space station remained among NASA's manned space flight goals for a time, but the commitment to Apollo in mid-1961 effectively pushed it into the indefinite future, simply because there was no time to build one for the lunar landing programme.

Dedication of the nation's manned space effort to a lunar landing realised Wernher von Braun's oldest professional ambition: to participate in extraterrestrial exploration. Few individuals had promoted such a venture with his single-mindedness and few had formulated the necessary steps in such detail [10]. When his group was incorporated into NASA in 1960 as the George C. Marshall Space Flight Center (MSFC), they brought with them the concepts for the launch vehicles that would send spacecraft to the Moon, along with the plan (Earth-orbital operations) for that voyage.

Von Braun headed the most experienced group of rocket propulsion experts in the Western World, but there can be no doubt that he would have liked to have MSFC develop manned spacecraft as well. In NASA, however, spacecraft development was the province of the Space Task Group, created at Langley Research Center in 1958 to manage Project Mercury and moved to Houston in 1963 as the Manned Spacecraft Center. If Apollo was to have any chance of being completed in the time allotted, this division of labour was necessary; von Braun yielded to necessity, but never gave up hope that his centre would develop expertise in other areas.

* *This paper is a slightly expanded version of the prize essay in the 1983 Robert H. Goddard Historical Essay Competition, sponsored by the National Space Club of Washington, DC, whose permission to publish is gratefully acknowledged.*

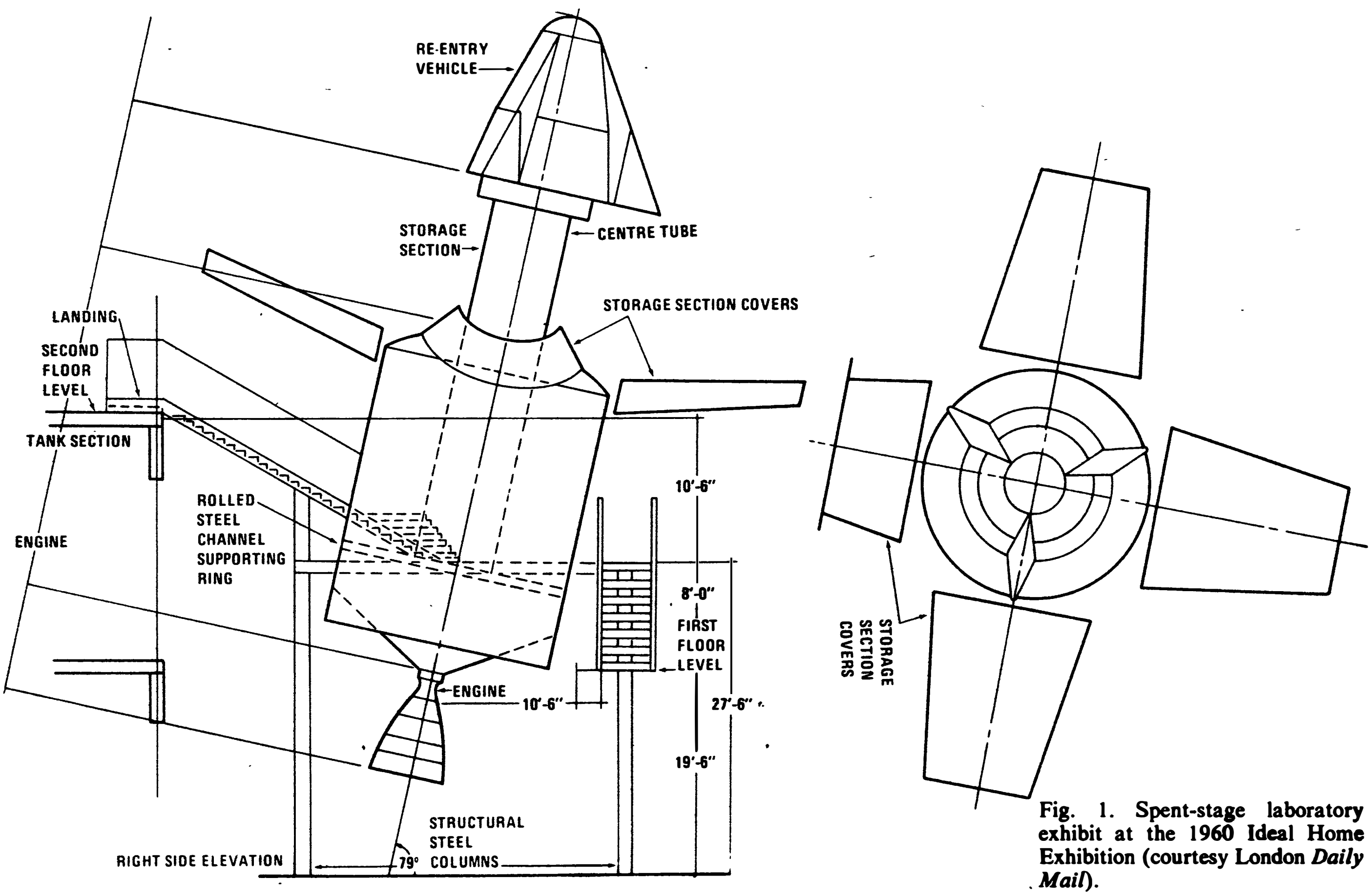

Fig. 1. Spent-stage laboratory exhibit at the 1960 Ideal Home Exhibition (courtesy London *Daily Mail*).

3. DOUGLAS AIRCRAFT CONSIDERS THE SPENT STAGE

Similar feelings motivated executives at Douglas Aircraft. Their company had won some launch vehicle contracts, but it had never been successful in competing for manned spacecraft. In 1962 Douglas chartered a study group to determine how the company might gain a foothold in the manned programmes [11]. This group soon decided that small orbiting laboratories were appropriate areas for the company to concentrate on; these could provide, at little cost, much information that NASA's advanced programmes would need but that would not be available from the projects then in prospect [12].

In its early discussions this group conceived of converting a spent S-IV stage into a laboratory that could support two men for 100 days in Earth orbit. Using a Gemini spacecraft launched on a Saturn I, a spent-stage laboratory could be developed within three years at a cost of $220 million. The main purpose of the laboratory was to investigate the physiological reactions of men to prolonged weightlessness, but other scientific and engineering research could be conducted as well. Douglas detailed these plans in an unsolicited proposal submitted to MSFC in November 1962; a few months later they submitted a revised proposal which used the larger S-IVB stage (see Roger E. Bilstein, 'From the S-IV to the S-IVB: The Evolution of a Rocket Stage for Space Exploration,' *JBIS*, **32**, 452 (1979).) being developed for the uprated Saturn I (the IB) launch vehicle [13].

No one seems to know exactly how the Douglas study group hit upon the spent-stage idea. Some years later the engineer who headed the group, Ted Gordon, could not recall where the idea originated [14]. According to von Braun, it was proposed by engineers at MSFC, 'who were thinking along similar lines (but had not documented their ideas) at the time' [15]. One of von Braun's aides has suggested that von Braun might have discussed such an idea with Douglas engineers as early as 1960 [16]. Curiously, Gordon was not aware that his own company had designed a spent-stage laboratory for the London Ideal Home Exhibition two years earlier [17].

At the time NASA had no use for a spent-stage laboratory and the proposal was shelved. But over the next few years Douglas engineers elaborated many possible uses for spent S-IV and S-IVB stages [18]. The company later conducted NASA-funded studies for small orbiting laboratories similar to their S-IV proposal and in 1965 it won the prime contract for the Air Force's Manned Orbiting Laboratory (MOL) [19], a two-man space station that was cancelled four years later.

4. APOLLO APPLICATIONS

Two critical decisions were necessary to bring Apollo's plans into line with the end-of-the-decade timetable and both had consequences that shaped post-Apollo programmes. The first, made in mid-1962, was the choice of lunar-orbit rendezvous as the mission mode [20] rather than Earth-orbit rendezvous, the mode for which von Braun and his centre had campaigned vigorously. The second, a year and a half later, was that the Saturn V Moon rocket would be tested from the beginning with all three stages functioning and all systems operational; there would be no stage-by-stage testing of many vehicles, as MSFC had done with Saturn I [21]. While MSFC agreed that both decisions were necessary, both were bad news for the centre, for they drastically reduced the scope of the launch vehicle projects that were

at that time MSFC's sole activity.

Future plans for manned space flight were also profoundly affected by foreign problems and domestic unrest in the mid-1960's. Many thoughtful Americans considered the priority given to multimillion-dollar space ventures to be unwarranted in light of the many problems in American society [22]. Closely related to this concern was a strong anti-technological sentiment that began to develop in the country early in the decade. Most notably manifested in a growing concern for the quality of the natural environment, this sentiment was expressed as active hostility toward heavy industry for its pollution of air and water, opposition to the construction of nuclear power stations, and pronounced antipathy toward large technological projects (such as the space programme) generally. Congress remained committed to winning the 'space race' and did not dismantle Apollo, but in 1963 it trimmed NASA's budget request by 10% and sent clear signals that costly proposals for future manned projects would be closely scrutinised.

NASA Administrator James E. Webb stood by his agency's commitment to land men on the Moon by 1970, but he became extremely reluctant to propose bold new programmes. Webb's position had always been that NASA should develop an unexcelled capability to operate in space and would propose a range of programmes that could be pursued, but that Congress and the nation should choose among them [23]. In the last years of his tenure Webb steadfastly refused to commit NASA to any specific post-Apollo manned projects.

His associate administrator for manned space flight, George E. Mueller, was forced into a difficult situation. Soon after he took over the manned space flight programme office in 1963, Mueller saw that he needed a commitment to a post-Apollo project, because it took years to get a new activity under way. Without definite post-Apollo plans, the superb manned space flight organisation so expensively created could not be held together. The Saturns required by Apollo were well along in production and no new launch vehicles were on the drawing boards, and Mueller could foresee a bleak future for MSFC, the largest of the manned space flight centres, unless it could begin work on something new [24]. Other centres faced similar problems, but much farther down the road.

Lacking a firm mandate for a new programme, Mueller decided to base his appeal to Congress and the public on practical utilisation of NASA's expensive manned space flight facilities. He also wanted to demonstrate that man could do significant work in space, thereby parrying some of the criticism heaped on his programme by scientists [25]. After a year of studies to establish the operational limits to which the Apollo system could be extended, Mueller devised a programme called 'Apollo Applications,' a scheme to use the rockets, spacecraft and launch facilities already developed for the lunar landing to conduct space research, including basic science but strongly emphasising practical projects whose results would benefit mankind [26]. Such a programme would, as Mueller saw it, produce a tangible return on the massive investment (estimates ranged from 20,000 million dollars upward) that the country had made in Apollo. The Apollo Applications Programme (AAP) was not enthusiastically received on Capitol Hill, but Mueller established an office at Headquarters to coordinate any projects that might fall within its scope [27] and kept up the planning activity while he campaigned for support.

5. MARSHALL SPACE FLIGHT CENTER EXAMINES THE SPENT STAGE CONCEPT

No one was more aware of manned space flight's uncertain future after Apollo than Wernher von Braun. From 1962

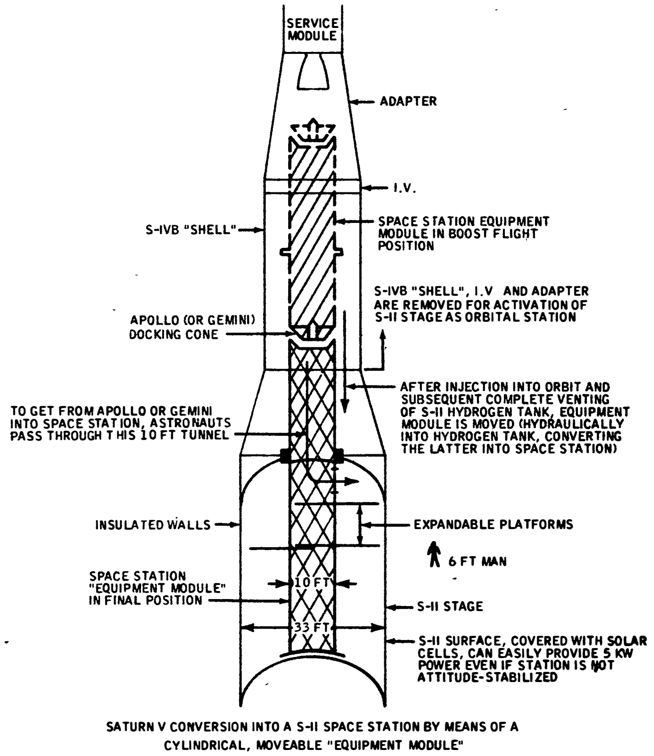

Fig. 2. Von Braun's idea for converting an S-II stage into a workshop. The S-IVB stage on the Saturn V would be replaced by a supporting shell of identical size. Redrawn from a sketch bearing von Braun's handwritten annotations (this and all subsequent figures reproduced by courtesy of NASA).

onwards, von Braun had MSFC's Future Projects Office exploring every conceivable possibility for effective use of its facilities, staff and industrial contractors [27]. In 1964 the spent-stage orbiting laboratory re-emerged as a promising concept, with both the S-IVB and S-II stages (Fig. 2) being considered. After getting a second, favourable evaluation of the S-IVB spent-stage laboratory [29], the Future Projects Office put together a presentation showing what could be done with an empty S-IVB stage and von Braun took it to Headquarters in July 1965.

MSFC's proposal began with a simple experiment to be conducted on one of the early Earth-orbital flights of the Apollo command module. It started with the simplest possible use of a spent stage: conducting basic experiments concerning mobility and restraint in null gravity. The plan called for a simple airlock and docking drogue to be fitted on top of an S-IVB stage. On reaching orbit, the command module would dock with the airlock and, after the stage was purged of residual propellant, the suited astronauts would remove the circular plate that closed the S-IVB and enter the fuel tank. There, protected from the hazards of free space, they would test various restraint devices and hand tools and experiment with personal mobility and transfer of bulky objects, recording the results on film for later study (Fig. 3). The proposal went on to show how the spent stage (or 'orbital workshop,' as it was called) could be converted to pressurised living quarters in which three astronauts could live and work for as long as 28 days [30].

This was precisely the kind of idea that Mueller had in mind for Apollo Applications, so he was naturally interested in it. More than that, Gemini mission planners were just beginning to consider extravehicular activity and knew almost nothing about its potential difficulties [31]; this may

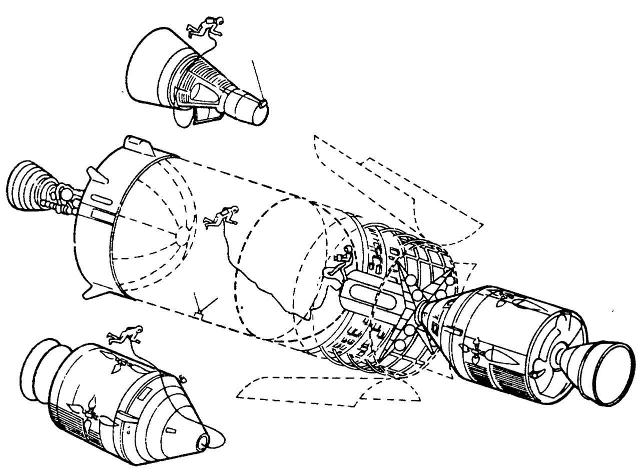

Fig. 3. S-IVB spent stage with Apollo CSM docked to airlock; concept of July 1965. Suited astronauts experiment with EVA techniques inside. Gemini (above) and Apollo (below) spacecraft shown for comparison.

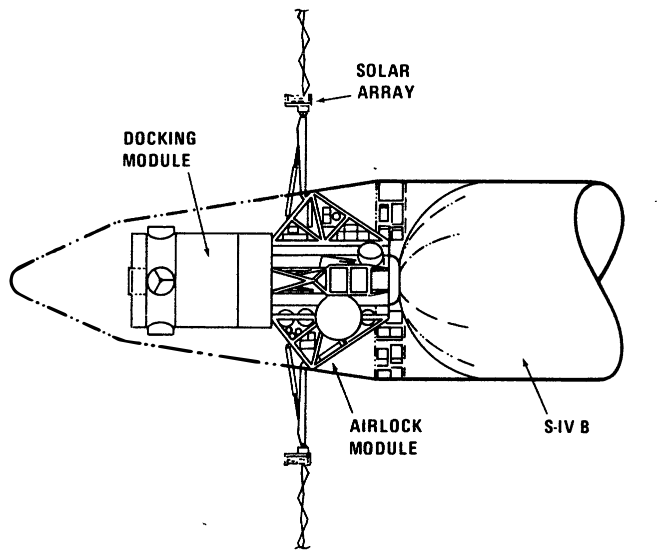

Fig. 4. Airlock and multiple docking adapter concept, late 1967.

have made the spent-stage proposal more attractive. A further attraction was that it could provide useful work for MSFC's engineers and contractors. In any case, Mueller was favourably impressed by the presentation and von Braun returned to MSFC with a commitment for $150,000 to support a four-month conceptual design study [32]. By the end of August the study was under way [33].

The S-IVB was an excellent candidate for conversion to a workshop. Its upper end, nearest the spacecraft, was a hemispherical dome having a 71 cm circular opening covered by a 'dollar plate' bolted on from the outside. Below this was the liquid hydrogen tank, the larger of the two tanks comprising the stage. More than 9 m long and 6.5 m in diameter, it enclosed just over 283 m³ of unobstructed space – as much volume as a small three-bedroom house [34].

The MSFC team had sketched out three versions of the orbital workshop: an unpressurised version, suitable only for short-duration exercises by suited astronauts and relying on the Apollo spacecraft for power and attitude control, and two pressurised versions providing a 'shirt-sleeve' environment that could support the crew for 14 to 28 days. All versions required changes to the S-IVB: provision for venting excess hydrogen and sealing the openings in the tank, elimination of hazards inside the tank, drilling and tapping holes in the tank wall to allow mounting equipment, and modifications to the stage's fuel-burning programme to stabilise its orbit. The advanced versions also required systems for electrical power and attitude control [35].

One major problem surfaced early when it was noted that a suited astronaut could not squeeze through the opening in the forward end of the S-IVB. Fortunately for the workshop study (which had no funds to modify the stage) MSFC's Saturn programme office uncovered a different problem with the tank opening that autumn. In some completed stages, cracks had developed around the opening. When Douglas found that enlarging the hole was one way to relieve the stresses that caused the cracks, von Braun chose that alternative with the spent-stage workshop in mind. All subsequent S-IVB's were built with 109 cm openings, a diameter based on the dimensions of a space-suited astronaut [36].

6. THE SPENT STAGE INCORPORATED INTO APOLLO APPLICATIONS

Workshop definition proceeded during the autumn, with continuing encouragement (but not funding) from Head-

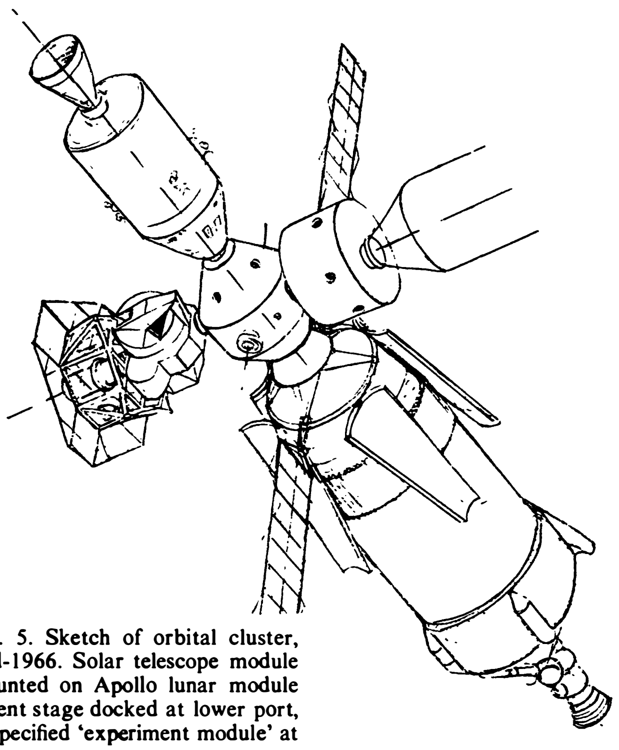

Fig. 5. Sketch of orbital cluster, mid-1966. Solar telescope module mounted on Apollo lunar module ascent stage docked at lower port, unspecified 'experiment module' at upper port.

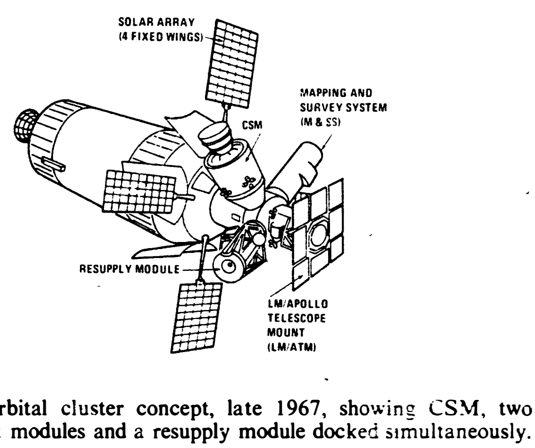

Fig. 6. Orbital cluster concept, late 1967, showing CSM, two instrument modules and a resupply module docked simultaneously.

quarters. By the end of 1965 Mueller had decided to commit the Office of Manned Space Flight to the orbital workshop as a major part of AAP. He directed MSFC to develop a plan for a 28-day mission to be flown in early 1968, using the most advanced version of the workshop [37]. With that under way, he could go to Congress in the spring of 1966 to campaign for funding AAP as a major programme. In December 1965 von Braun upgraded the workshop activity from a conceptual design study to a project and the following March a Saturn/Apollo Applications Office was opened at MSFC to oversee the workshop and its experiments [38].

6.1 Problems of Apollo Applications, 1965-1969

Webb had found little to like in the early Apollo Applications plans and had declined to give it a place in NASA's budget proposals until fiscal 1967. In the interim (and in fact until the first Apollo lunar landing) AAP was the stepchild of the manned space flight family whenever NASA got into a tight spot for money – as is did year after year. To accommodate the cutbacks, mission plans were changed and launch dates postponed while Apollo approached its culmination. One Headquarters joke characterised AAP as the programme that was always two years away from its first launch; another said that the initials 'AAP' stood for 'Almost a Program.'

There was the further problem that, within the manned space flight organisation, only Mueller and von Braun were enthusiastic supporters of the workshop project. The Manned Spacecraft Center (MSC), fully occupied with Gemini and Apollo, could participate only marginally in AAP but consistently objected to it – in part because they regarded it as an ill-conceived project that would contribute little to the advancement of space technology, in part because they considered it technically and operationally unsound and inferior to alternatives that MSC could conceive and (it must be concluded) in part because it was a manned project for which MSC did not have primary responsibility.

6.2 Evolution of the Spent-Stage Concept

Throughout the formative years the spent-stage workshop remained the core of the Earth-orbital programme*. During 1966 project planners began to focus on leaving the unoccupied workshop in orbit to be resupplied and revisited by successive crews. When the year ended the workshop had evolved into an 'orbital cluster' comprising the workshop, an airlock and a module (the multiple docking adapter) to which the Apollo spacecraft and various experiment and supply modules, could be attached (Figs. 4, 5 and 6). Two missions were more or less firmly planned; they would take three-man crews to the workshop for flights lasting 28 and 56 days. The major purpose of these flights was to investigate the physiological effects of prolonged exposure to null gravity, but the flight plans included engineering and scientific experiments as well. A set of sophisticated solar telescopes was under development, which Mueller believed would show that a man trained to use his judgement in operating instruments could enhance the value of astronomical observations [39]. The spent-stage experiment had evolved into a small space station, more complex than the simple shelter for manoeuvring experiments that MSFC had originally proposed.

* *It was not, however, the only operation planned for AAP. In the earliest projected launch schedules Earth-orbital missions using the wet workshop were interspersed with lunar exploration missions. In December 1967 a Lunar Explorations Programme Office was established and all missions to the Moon were subsumed in Apollo, leaving the Earth-orbital flights to AAP.*

6.3 Technical Problems with the Spent Stage

Modifying the S-IVB stage to serve the multiple purposes of AAP turned out to be a harder job than MSFC had expected. Most of the problems resulted from the necessity of using the S-IVB as a propulsive stage before it was converted into a workshop: anything that was to be inside the workshop at launch had to be able to survive immersion in liquid hydrogen at -254°C (-425°F) and could not interfere with the flow of fuel to the engine. The instruments to be used by the medical experimenters, for example, could not be installed in the tank before launch and thus had to be carried in the multiple docking adapter, to be moved into the workshop after the crew reached orbit. Since the experimenters wanted to begin gathering medical data on the crew as soon as they encountered weightlessness, these instruments had to be designed to be operated in the multiple docking adapter as well as in the workshop – a constraint that proved very difficult to overcome [40]. There was the further difficulty that moving this equipment into the spent stage and setting up the workshop constituted a work load that would interfere with the medical measurements and might prove too taxing for the astronauts.

Creating a living and working environment within the fuel tanks was somewhat easier – but only a little. MSFC engineers designed an open aluminium grid to serve as a floor and folding sheet-metal partitions to divide the workshop into compartments for sleeping, personal hygiene and food preparation (Fig. 7). Problems arose when George Mueller took exception to the barren mechanical appearance of the workshop. 'No one could have lived in that thing for more than two months,' he later remarked, 'they'd have gone stir-crazy' [41]. He insisted that MSFC hire an industrial design consultant to give the workshop a more pleasant ambiance. The New York firm of Raymond Loewy/William Snaith, Incorporated was engaged to study the workshop design and make recommendations [42]. Loewy's first suggestion was to improve the lighting and finish the interior in cheerful colours rather than the drab olive-green of the early mockups [43]. This was a major headache, for the range of finishes that were available in the recommended colours and could stand immersion in liquid hydrogen was limited [44].

7. ALTERNATIVES TO THE SPENT STAGE

As the limitations of the spent-stage workshop became more and more apparent, Mueller and others began to seek alternatives that would circumvent them without destroying AAP entirely. The programme itself seemed acceptable though somewhat pedestrian, but the means to carry it out was marginal. Little could be done within the fiscal constraints of 1966-1969 and James Webb, fearful of risking NASA's support in Congress, would not recommend an expensive new laboratory more suited to AAP's specific purposes. The only option that seemed to have any chance of acceptance was the so-called 'dry' workshop: an S-IVB stage modified and equipped before launch as a workshop but never used as a propulsive stage [45]. The major objection to the dry workshop was that only a Saturn V could put it into orbit, whereas the original 'wet' workshop could be launched on a much less expensive Saturn IB. This idea was scarcely worth proposing, because Webb had only with great difficulty persuaded Congress to pay for 15 Saturn V launch vehicles, and he refused even to consider diverting one from the Apollo programme until he was certain Apollo would

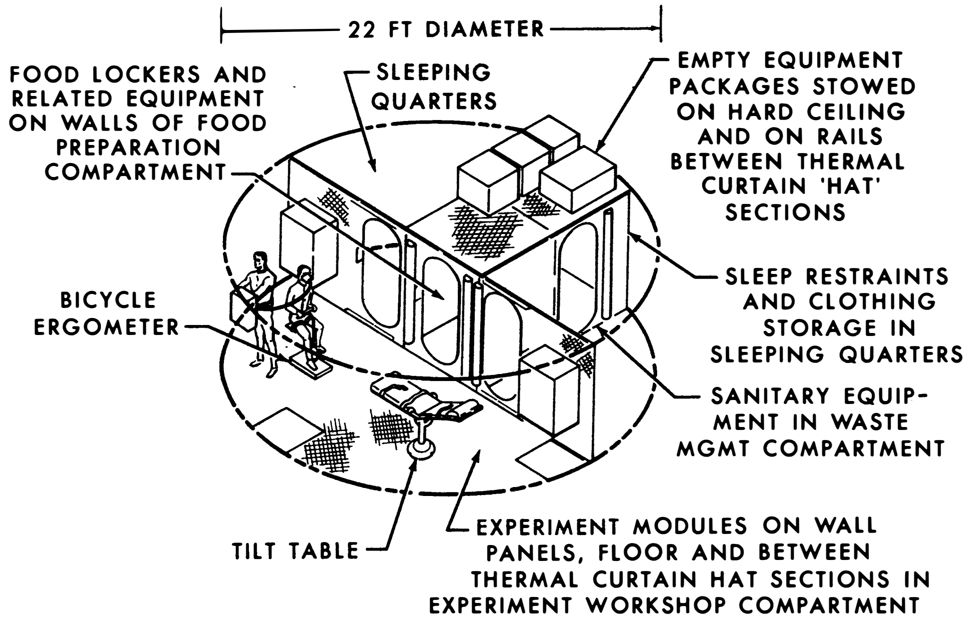

Fig. 7. 1966 concept for compartmentalising the spent stage. Sheet-metal 'floor' and 'ceiling' panels were folded against interior walls at launch. Main compartment floor, in place at launch, was a grid with 10 cm triangular openings machined from 3 cm aluminium plate.

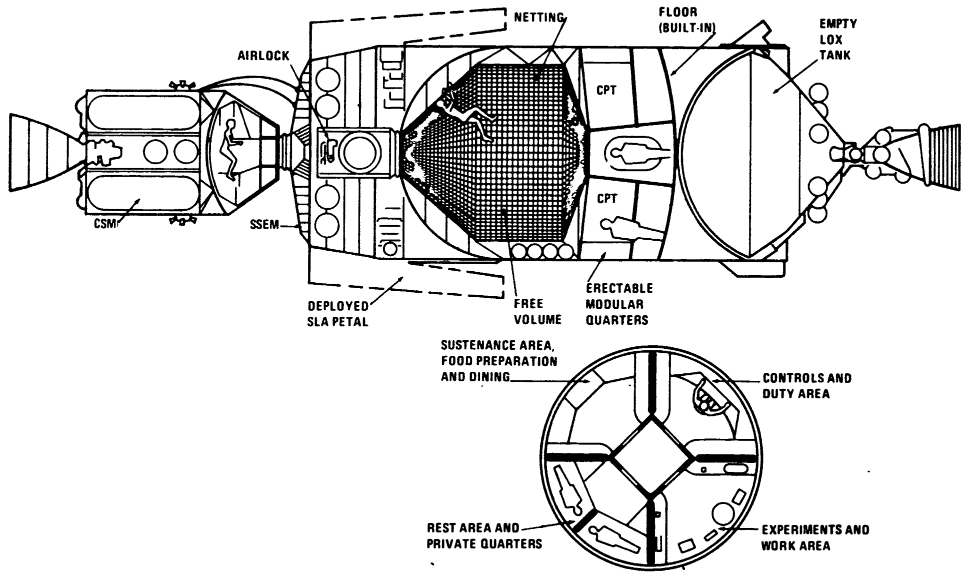

Fig. 8. Spent-stage workshop, early 1967, showing division of interior into compartments.

succeed.

But Webb resigned from NASA in the autumn of 1968, less than a year before the first lunar landing [46] and his successor, Thomas O. Paine, advocated a much bolder space programme. By early 1969 the dry workshop was under serious consideration [47]. Studies indicated that its advantages would be worth the added cost, which was considerable. Now, however, MSFC objected, citing the substantial shuffling of manpower and the resulting delays that could disrupt the programme. All the wet-workshop scheme needed, said von Braun, was a 'hard-nosed scrubbing down' to make it work [48]. But events had overtaken the spent-stage laboratory (Fig. 8), and on 22 July 1969, as the Apollo 11 astronauts were on the way back from the Moon, it was abandoned and AAP was based on the dry workshop [49]. The following February a much-streamlined AAP acquired a new name, Skylab, and three and a half years later, on 14 May 1973, the first mission was launched (Fig. 9), initiating a three-mission programme that would set new endurance records for orbital flight and produce an extraordinary array of experimental results [50].

8. THE SPENT STAGE: AN EVALUATION

Von Braun's spent-stage concept was once more put aside, a victim of the changing climate in which manned space flight operated. This idea was not completely without merit, but probably only the original primitive wet workshop, had it been flown as early as initially planned, would have contributed significantly to the manned space programme. What really killed the wet workshop was the peculiar position AAP came to occupy in the sequence of manned missions. By 1968 the Vietnam war and President Lyndon Johnson's social programmes were creating severe pressure of the federal budget and space projects were prime targets for economising. AAP was the least expensive of the few alternatives that NASA had for post-Apollo manned projects. A new start using some completely different concept was out of the question, as even MSC acknowledged. The more it appeared that AAP would be the last manned space flight project for an uncomfortable number of years, the more managers wanted to cram into it, until eventually the experiments overloaded the flight plan as well as the Saturn

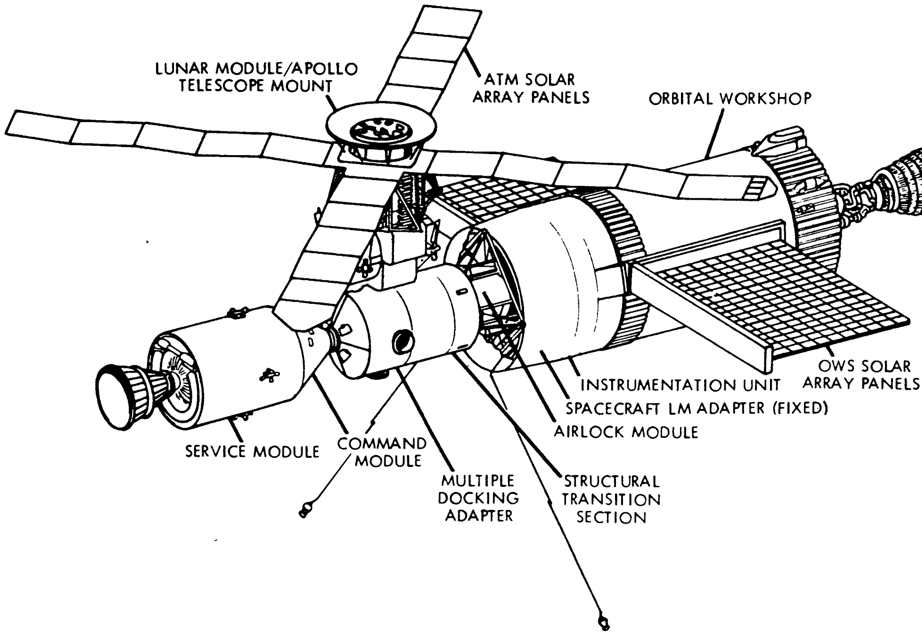

Fig. 9. Orbital cluster, final configuration (late 1968). LM-mounted solar telescope module was discarded in 1969 in favour of an integrally mounted module launched with the workshop, airlock, and multiple docking adapter; otherwise this drawing is nearly identical with the Skylab workshop as launched in 1973.

IB launch vehicle. Some experiment plans had progressed so far during the wet-workshop days, however, that the dry workshop was the best way to accommodate them with minimum disruption of the programme. After Skylab's last mission had been flown, it was generally agreed that those experiments produced results that were worth the added cost.

But the spent-stage workshop concept refused to die. In 1976 some Marshall Space Flight Center engineers began considering how the 552 m^3 liquid oxygen tank proposed for the Shuttle Orbiter might be used as the core for a large permanent space station. The arguments were the same as those advanced in 1965 for the wet workshop: the tank was a spacious, sturdy structure that could be put into orbit but would otherwise be discarded, which could provide the nucleus of a permanent installation at a third to a half the cost of building a station from scratch [51]. But now that an American space station has been formally proposed and submitted as part of NASA's requested budget, the designers are starting with a clean sheet.

REFERENCES AND NOTES

Titles followed by the notation (WRC) are NASA documents filed in the manned space flight archives in the Woodson Research Center, Fondren Library, William March Rice University, Houston, Texas.

1. Roland W. Newkirk and Ivan D. Ertel, with Courtney G. Brooks, *Skylab: A Chronology,* NASA SP-4011, U.S. Goverment Printing Office (GPO), Washington, D.C., 1077, p. 10.
2. Wernher von Braun and Frederick I. Ordway III, *History of Rocketry & Space Travel,* rev. ed., Thomas Y. Crowell Company, New York, 1969, p. 135.
3. Newkirk and Ertel, *Skylab: A Chronology,* p. 10.
4. *Ibid.*
5. Roger E. Bilstein, *Stages to Saturn: A Technological History of Apollo/Saturn Launch Vehicles,* NASA SP-4206, GPO, Washington, 1980, p. 158.
6. 'Project Horizon, Phase I Report: Army Study for the Establishment of a Lunar Military Outpost,' US Army Ordnance Missile Command, Huntsville, Alabama, 8 June 1959, Vol. 1, p. 17 (WRC).
7. Wernher von Braun, letter to the present author, 6 March 1975.
8. Barton C. Hacker, 'The Idea of Rendezvous: From Space Station to Orbital Operations in Space-Travel Thought,' *Technology and Culture,* **15**, 373 (1974).
9. Project Horizon Report, pp. 129-130.
10. Wernher von Braun, 'Crossing the Space Frontier,' *Collier's,* 22 March 1952, pp. 24-29, 72-74; 'Man on the Moon: The Journey,' *ibid,* 18 October 1962, pp. 51-60; 'Man on the Moon: The Exploration,' *ibid,* 25 October 1952, pp. 38-48.
11. Ted Smith (McDonnell Douglas Astronautics Co.), telephone interview with the present author, 1 May 1975 (WRC).
12. Douglas Aircraft Co. (DAC) report no. SM-42587, '1965 Manned Space Laboratory Briefing Manual,' November 1962 (WRC).
13. *Ibid;* DAC report no. SM-43257, 'S-IV/S-IVB as Manned Space Laboratory,' February 1963 (WRC).
14. Ted. J. Gordon, telephone interview with the present author, 22 May 1975 (WRC).
15. Wernher von Braun and Frederick I. Ordway III, *History of Rocketry & Space Travel,* 3rd ed., Thomas Y. Crowell Company, New York, 1972, pp. 277; von Braun, letter to the present author, 6 March 1975.
16. Heinz H. Koelle (Technical Univ. of Berlin), letter to the present author, 2 July 1975.
17. Gordon interview.
18. Ted J. Gordon and W. H. Siegried, 'Keys to "Economical" Space Flight: Saturn Hardware and Reusable Boosters,' *Space/Aeronautics,* March 1963, pp. 93-95; Carl M. Hanson and C. Allen Gilbert, 'Utilization of Expended Booster Stages for Manned Space Laboratories,' presented at the Aviation and Space, Hydraulic, and Gas Turbine Conference of the American Society of Mechanical Engineers, Los Angeles, 3-7 March 1963; M. W. Root, 'Application of Saturn/S-IV/S-IVB Systems to Planetary Exploration,' DAC engineering paper no. 3645, presented at the Symposium on Post-Apollo Exploration, American Aeronautical Society, Chicago, 4-6 May 1965; DAC report pp. 148, 'A Low-Cost Technique for Land Recovery of an S-IVB Stage from Orbit,' February 1966; DAC presentation at Marshall Space Flight Center, 'S-IVB Spent Stage Applications,' 11 March 1966; DAC report no. SM-53131, 'Saturn S-IVB Stage Applications (Part I), Block I Study, Volume I, Summary Report,' 6 April 1966; DAC report no DAC-56365P, 'Lunar Applications of a Spent S-IVB/IU Stage (LASS),' September 1966; DAC-IBM study PP-161, 'Lunar Applications of a Spent S-IVB/IU Stage in Orbit (LASSO),' November 1966; DAC report DAC-57996, 'Feasibility of Modifying the S-IVB Stage as an Injection Stage for Manned Planetary Flyby Missions,' May 1967.
19. *Astronautics and Aeronautics, 1965: Chronology on Science, Technology and Policy,* NASA SP-4205, GPO, Washington, 1966, p. 396.
20. Courtney G. Brooks, James M. Grimwood, and Lloyd S.

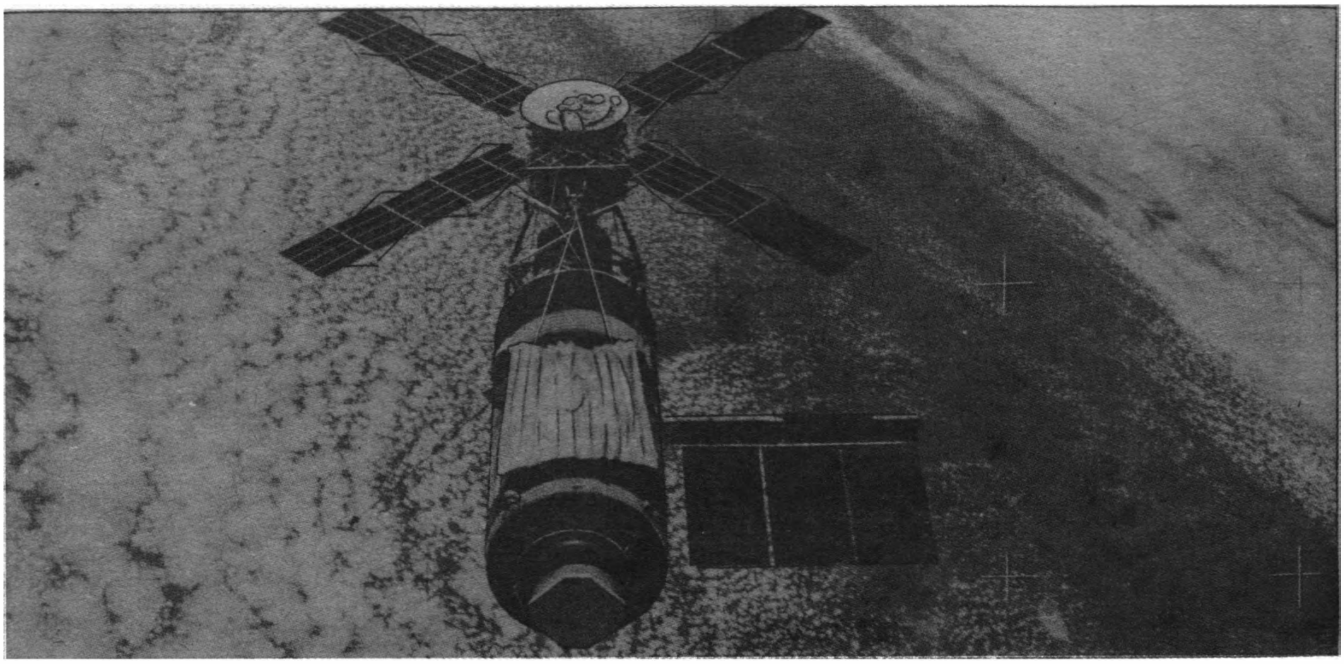

Fig. 10. Skylab in orbit, 1973. A design flaw resulted in an accident at launch; the thin meteoroid shield, which also served to control solar heating of the workshop, was ripped off, taking with it one of the workshop solar-cell arrays. An improvised 'parasol', seen in this photograph, replaced the lost heat shield. See J. von Puttkamer, 'Skylab: Its Anguish and Triumph,' *JBIS*, **35**, 541 (1982).

Swenson, Jr., *Chariots for Apollo: A History of Manned Lunar Spacecraft*, NASA SP-4205, GPO, Washington, 1979, pp. 77-86.

21. Bilstein, *Stages to Saturn*, pp. 348-351.
22. The various objections are adequately represented in U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, 'Scientists' Testimony on Space Goals,' hearings, 88th Cong., 1st sess., 10-11 June 1963.
23. U.S. Congress, Senate, Committee on Aeronautical and Space Sciences, 'National Space Goals for the Post-Apollo Period,' hearings, 89th Cong., 1st sess., 23-25 August 1963, pp. 12-13, 30.31.
24. George E. Mueller, interview with the present author, 26 August 1975 (WRC).
25. Mueller's first public description of AAP is found in U.S. Congress, House, Subcommittee on Manned Space Flight of the Committee on Science and Astronautics, '1967 NASA Authorization,' hearings on H.R. 12718, 89th Cong., 2nd sess., part 2, pp. 163-184.
26. W. David Compton, 'Science and Manned Spaceflight: The Skylab Experience,' *JBIS*, **32**, 463 (1979).
27. House subcommittee hearings cited in note 25, pp. 260-261.
28. F. L. Williams (NASA Hq), interview with the present author, 15 July 1975 (WRC).
29. North American Aviation, Inc., 'Utilization of Spent Launch Vehicle Stages in Support of Earth Orbital Missions,' report under contract NAS8-11379, vol. III, pp. 59-60, 31 May 1965.
30. MSFC presentation to OMSF Management Council, 20 July 1965 (WRC).
31. Barton C. Hacker and James M. Grimwood, *On The Shoulders of Titans: A History of Project Gemini*, NASA SP-4203, GPO, Washington, 1977, pp. 248-50, 304-306.
32. E. Z. Gray (NASA Hq), letter to Maxime A. Faget (MSC), 16 August 1965, with encl., 'Proposed MSF Advanced Study Program, FY 1966,' (WRC).
33. J. H. Laue (MSFC), memo to multiple addresses, 'Minutes of August 25, 1965, S-IVB Orbital Workshop Conceptual Design Study Meeting,' 30 August 1965 (WRC).
34. Bilstein, *Stages to Saturn*, pp. 161-162.
35. Laue, 'Minutes of... meeting,' 30 August 1965.
36. Smith interview; Wernher Kuers (MSFC), '[Weekly] Notes [to von Braun],' 26 July 1965 (WRC); von Braun, annotation on Kuer's 'Notes' of 28 June 1965 and on Stanley Reinartz's 'Notes' of 8 November 1865 (WRC); DAC report PP-144, 'S-IVB Hydrogen Tank Dome Access Opening Modification Program,' 12 October 1965; memo, Hans Hueter (MSFC) to von Braun, 4 November 1965 (WRC).
37. F. L. Williams (MSFC), memo to multiple addressees, 'S-IVB Workshop Activities,' 6 December 1965 (WRC); J. T. Shepherd (MSFC), memo to multiple addressees, 'S-IVB Workshop,' 1 December 1965 (WRC).
38. George E. Mueller (NASA Hq.), letter to von Braun, 1 July 1966 (WRC).
39. NASA, 'Apollo Applications [Press] Briefing,' 26 January 1967, transcript (WRC).
40. OMSF, 'MSC AAP Earth Orbital Flight Review (SLA-Lab Presentation), Washington, D.C., 18 November 1967, Summary of Verbatim Tape Record,' no date (WRC).
41. Mueller interview.
42. MSFC, 'Work Statement for an Industrial Engineering Design Consultant Covering Effort for Design Consultation on Habitability Aspects of Earth Orbital Space Stations,' 1 December 1967 (WRC).
43. Raymond Loewy/William Snaith, Inc., 'Habitability Study, AAP Program,' February 1968 (WRC).
44. W. K. Simmons, Jr. (MSFC), interview with the present author, 30 October 1974 (WRC).
45. AAP Office (NASA Hq.), 'Consideration of Saturn V in Place of IB for Launch of AAP Orbital Workshop,' presentation to OMSF Management Council, 4 February 1962 (WRC). The dry workshop idea was not new; it appeared as one of the later AAP missions in the earliest AAP launch readiness schedules.
46. Neil Sheehan, 'Webb Quits as Head of Space Agency; Notes Soviet Lead,' *New York Times*, 17 September 1968.
47. L. F. Belew (MSFC), memo to von Braun, 'Wet/Dry Workshop Discussions at the OMSF Hideaway Meeting,' 1 May 1969 (WRC).
48. Von Braun, letter to George E. Mueller, 23 May 1969 (WRC).
49. W. C. Schneider (NASA Hq.), telex message to MSC, MFSC and KSC AAP managers, 22 July 1969 (WRC).
50. For the full story of the spent-stage concept, the AAP programme, and the Skylab project that grew out of them, see W. David Compton and Charles D. Benson, *Living and Working in Space: A History of Skylab*, NASA SP-4208, GPO, Washington, 1984.
51. Dave Dooling, *'Super Skylab: Marshall Space Flight Center Engineers Propose Shuttle Tank As Orbit Base,' The Huntsville Times*, (Alabama) 20 February 1977.

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PIONEERING COMMERCIAL ROCKETRY IN THE UNITED STATES OF AMERICA, REACTION MOTORS, INC. 1941-1958, PART 2: PROJECTS

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The December 1983 Astronautics History issue of *JBIS* related the corporate history of Reaction Motors, Inc. (RMI), with brief mention of projects undertaken from 1941-1958. Part 2 deals in more detail with these developments. The final and third part of the RMI story will cover the history of the Reaction Motors Division of the Thiokol Chemical Corporation 1958-1970.

1. JATO

The idea of the rocket as an auxiliary powerplant for aircraft hardly originated with RMI. Perhaps the earliest concept for Jato (Jet-Assisted-Take-Off) was conceived by T. J. Bennett of Oxford, England in the 1880's. Bennett made a 30 lb (13.6 kg) model of a steam-propelled aircraft but quickly realised that his steam engine was underpowered for a rapid take-off from a short surface. His solution was to provide an initial boost to the model by means of gunpowder rockets. "The starting was very successful," he recalled years later, "I wish I could say the same of the subsequent flight" [1].

H. H. Bales of Ashcroft, British Columbia, Canada, took out probably the first Jato patent in which he, too, incorporated skyrockets attached to an aircraft. This was US patent No. 1,003,411, 19 September 1911, for a "Pyrotechnical Auxiliary Propelling Mechanism." Other patents followed, such as one by the French aviator Albert Lepinte (British specification No. 229,670 of 19 February 1924 with a later US patent, No. 1,611,353 of 21 December 1926). Lepinte envisaged extra power from rockets more as a safety feature: rockets could be reversed so that they retarded an aircraft's rapid descent or accelerate the 'plane in time of danger. (A dramatic drawing of Lepinte's deaccelerating rockets in action may be found in the French magazine *Je Sais Tout*, 24 Année, June 1928, p. 170.) The idea was certainly in the air at this time because in the USSR, V. I. Dudakov and V. A. Konstantinov took out their own patent on 8 October 1928 for the "Construction of Rocket Engines for Powered Aircraft Flight," which in essence was also a Jato [2].

These gentlemen may or may not have known of probably the first full-scaled successful Jato flight made on 8 August the following year when a Bremen Type Junkers W33 land 'plane fitted with floats took off from the Elbe River near Dessau, Germany, using six powder rockets ignited rapidly in pairs. Although the Junkers firm was convinced it would one day be possible to use rocket assist to lift the then large load of 11,000 lb (5,000 kg), follow-up experiments did not come until much later. In any case, Dudakov and Konstantinov continued their own researches for the Soviet Army-supported Gas Dynamics Laboratory (GDL). Their solid-fuel rocket assisted flights began in 1931, first with a U-1 light aircraft, then afterwards with TB-1 bombers. They later progressed to liquid-fuel Jatos, but these developments were totally unknown outside the USSR and have only recently come to light.

Most likely, the highly sensational rocket-assisted glider stunts of 1928-1929 by the colourful German automobile manufacturer Fritz von Opel was the catalyst that precipitated serious Jato researches. Besides the USSR, the military services of Germany, the US, Great Britain, Japan and Poland were undertaking Jato development in earnest by the mid-1930's, *albeit* some of these programmes were short-lived [3].

The earliest American Jato work is of particular interest in the RMI story. The US Army was generally apathetic towards rocket weapons in the 1930's but the Air Corps branch did support the famous GALCIT (Guggenheim Aeronautical Laboratory of the California Institute of Technology) and its efforts to develop practicable rockets from 1938, including Jatos. The GALCIT work led to the formation of the Aerojet Engineering Corporation in 1942 and the Jet Propulsion Laboratory (JPL) in 1944, both of which initially conducted Jato manufacture and development. (Aerojet, the US's second pioneering commercial rocket corporation was similarly interested in multiple applications of rocket power but responded to the immediate wartime need for Jatos on heavily-laden military aircraft.)

Whereas Aerojet's principal customer for this product was the US Army Air Corps, the first and long-time customer for RMI was the US Navy. As pointed out in Part 1, RMI began shortly after the bombing of Pearl Harbor by the Japanese in 1941, and that even earlier (in November 1941), the RMI's future President Lovell Lawrence had succeeded in arranging for a test run of James H. Wyld's regeneratively cooled motor for a Navy representative.

Yet the Navy soon came to support not one but five liquid-fuel Jato projects simultaneously. These were: RMI; some work by Aerojet and GALCIT; a group headed by Dr. Robert H. Goddard; and the Navy's own research team headed by Lt Cmdr Robert C. Truax. Truax, who like Wyld had his original rocket engines tested on the American Rocket Society's proving stand No. 2, in 1938, began his own Navy Jato work late in 1941. Goddard signed his joint Navy and Army Air Corps contracts at about the same time but moved his personnel and equipment to the Naval Engineering Experiment Station at Annapolis, Maryland in July 1942. In fact, RMI and Truax also conducted their

Jato projects at the Annapolis station. (RMI was assigned a small building for part of their work in late November 1943.)

There were several reasons for this apparent duplication of efforts. In the first place, according to Lou Arata, one of the first shop workers hired by RMI, rocketry was then a wide-open field with so many variables that needed proving out that "even more groups or experimenters would have been welcome." Truax, both a Navy man and ardent rocket experimenter himself, confirms this view and adds that there was also tremendous pressure at the time because of the Pacific war so that the Navy was very anxious to "try as many different parameters and designs as possible for the greatest chance of success within the shortest time." As for stationing three of the five Jato groups at Annapolis, the reasons here were threefold: the facilities of the Naval Engineering Experiment Station (NEES) had been there for decades and could be put to good use on the Jato projects; the VN-8 Naval Seaplane Squadron for testing the Jatos was conveniently right next door, along the Severn River; and Annapolis was close to Washington, from where Navy Jato projects were administered [5]

The three Annapolis groups indeed offered different approaches and were always friendly and even helpful to each other. Goddard, for example, noted in his diary for 15 Sepetmber 1942: "Went with Lt. [C. Fink] and Mrs. Fischer to New Jersey, and saw the Reaction Motors setup. Had dinner with them and Lawrence and Shesta..." (C. Fink Fischer was RMI's liaison officer with the Navy.) Arata remembers occasional visits from Goddard and Truax and that the former loaned a pump to RMI. Unfortunately, it was defective and leaked! Nonetheless, Goddard's papers reflect a continued close and sincere association with both RMI and Truax throughout Goddard's Annapolis years until his death in 1945. On one or two occasions, Lawrence suggested a merger with Goddard, but without results [6].

The chief difference in approach to Navy Jatos was the choice of propellants. Goddard consistently favoured liquid oxygen (Lox) and petrol since he started with liquids in 1920. Truax, who had independently developed his own regeneratively-cooled rocket engine in the late 1930's, began with compressed air and petrol. When he switched to Goddard's combination he encountered ignition and combustion problems. Then, in 1942, a solution was found: one of his assistants, Ray C. Stiff, made the serendipitous discovery of the combination of nitric acid and aniline, which are hypergolic (they ignite spontaneously). Artificial means of ignition were not needed and combustion was smooth. Another advantage was that super cold liquid oxygen and associated cryogenic equipment did not have to be used – a boon for wartime military operations. In modern parlence, the propellants were "storable" or "packaged" in that they could be kept at room temperature. Greater specific impulse was also gained. On the negative side, the acid was extremely corrosive and did require certain special handling. Truax still made the shift to the hypergolic and was followed by Aerojet; but Goddard stubbornly clung to the standard Lox and petrol and he always objected to the acid's corrosiveness and toxicity.

To establish priorities, nitric acid as an oxidiser is alleged to have been tried as early as 1930 by Friedrich Sander in Germany, though he was more well known for his solid-fuel (gunpowder) motors. In 1932-33, the American Harry Bull tested nitric acid and turpentine, a mixture found to be not particularly smooth. The Germans secretly began to develop their own hypergolic mixtures from the late 1930's; Helmut von Zbrowski was the most prominent among the experimenters. These efforts culminated in projects such as the Wasserfall and Taifun missiles of the mid-World War II period. At RMI, this form of propellant was not fully investigated until the mid-1940's, when it was employed in the Navy's Gorgon II-A and Lark programmes [7].

RMI's original Navy contract for Jatos, Project TED-EES-3401, in early 1942, stipulated that the company deliver the existing Wyld regeneratively cooled liquid oxygen-alcohol motor. In addition, an identical, though 100 lb (45.4 kg) thrust liquid oxygen-petrol version was also to be demonstrated. The third and most important part of the contract called for the development of a 1,000 lb (454 kg) thrust Lox-petrol unit. This engine had to demonstrate repeated starts and was to be completed within 180 days.

In their own interests, the RMI founders felt it best not to deviate from the Lox-petrol staple, although the Wyld engine was designed only for the alcohol fuel. According to Shesta, "A replica of the original Wyld motor quickly burned out when tested with gasoline. This would never do. A complete re-design was necessary." Among the changes was a substitution of a copper nozzle for the former one machined from aluminium. This new motor was designated M15-G-1. RMI called it the Wyld Regeneratively-Cooled Rocket Motor Serial No. 2. It is now on exhibit in the National Air and Space Museum in Washington, D.C.

From this simple unit evolved several other small experimental motors, all of which were tested by RMI personnel on the American Rocket Society's test stand No. 2, which is also on display in the Museum. Since the stand had largely been designed by RMI founder John Shesta and had been built in co-founder Franklin Pierce's basement, it was easily "borrowed" by the fledgling company – especially after the Society ceased its experimental activities following the bombing of Pearl Harbor. This stand could statistically fire rockets up to 200 lb (90 kg) of thrust [8].

Eventually, RMI was compelled to build a larger stand. This was a permanent stand (ARS stand No. 2 was portable) anchored to a concrete slab at Franklin Lakes, New Jersey, and had an initial capacity of over 1,000 lb (454 kg) thrust. An adjacent blockhouse, which still exists and which was recently named an official historic landmark, was constructed 12 ft (3.7 m) away. A surviving handwritten RMI logbook indicates that Wyld had much to do with designing these testing facilities. One interesting feature was a moveable security shelter that was rolled over the stand when it was not in use, although the old German Rocket Society (VfR) erected a similar construction about 1933.

The Wyld serial No. 2 and similar small motors proved that petrol and Lox could adequately work in a regenerative system. The final motor of this series was run about 50 times for durations of a few seconds to more than a minute. Even as this work was conducted, progress was made toward the development of the 1,000 lb (454 kg) thrust motor. Because of its larger size, greater operating temperatures were anticipated. Consequently, stainless steel was chosen for the nozzle rather than copper. Drawing from his past experience with this material, Shesta designed a set of punches and dies. With these, and a hydraulic press located by Lawrence, "very satisfactory nozzles" were formed.

Lawrence was also responsible for developing remotely-controlled throttling valves operated by small electric motors and gears. Wyld and Lawrence applied for US Patent No. 2,479,888, on 6 July 1943, for their throttling system; a patent titled "Controlling System for Reaction Motors" was not granted until 23 August 1949 [9].

Spark plug or squib igniters often proved troublesome. In one test, the spark plug porcelain broke, causing a spray of oxygen to escape from the hole. Ignition delays, improper premixing of propellants and lack of ignition was frequent. Despite these problems, the 1,000 (464 kg) thrust unit was satisfactorily delivered to the Navy on schedule; although there is one RMI legend that the original engine blew up shortly before the qualification test was to be held and a replacement was built in record time.

By the time the 1,000 lb (464 kg) unit was finished, RMI

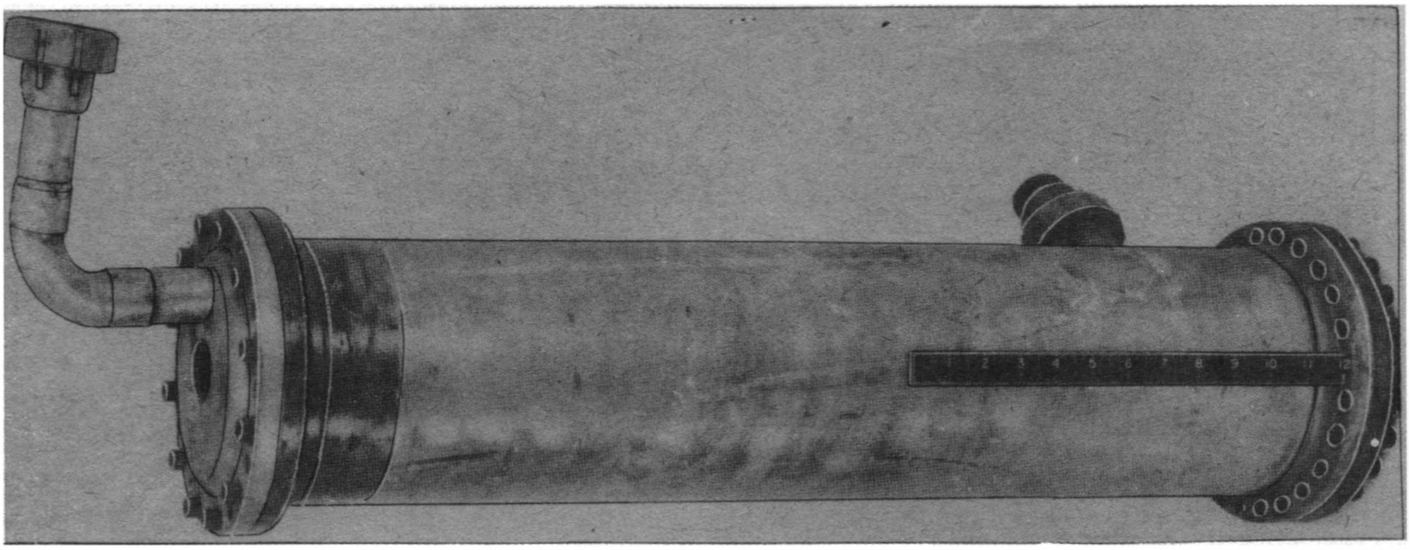

Fig. 1. RMI's 3000-A-1 rocket engine, a 3000 lb (1300 kg) thrust Jato unit for heavily loaded US Navy seaplanes, developed 1942-45.

had produced at least ten different models of motors (not including test blanks), ranging from 50 lb to 1,000 lb (23 to 464 kg). However, work was already proceeding with a 2,000 lb (900 kg) unit. This, too, was delivered to the Navy, which was now convinced that much larger models were feasible. A second contract called for a 3,000 lb (1360 kg) motor that was meant for installation in a Martin PBM patrol bomber [10].

Shesta made an interesting innovation in this new engine. He fitted a multi-hole (40 or more openings) oxygen injector into the injector plate. These holes were aligned concentrically with holes in the lower plate that fed the petrol. "These holes," Shesta reported, "protruded slightly past the lower plate, the annular space providing a clearance for a thin film of gasoline feed. As the oxygen emerged from the central hole, it spread out in a cone that intersected the annulus of fuel and provided good mixing."

Arata recalls that informality marked the early days of RMI, with the modifications of designs and techniques such as those worked out over lunches or coffee breaks at the nearby Triangle Grill. "Usually," he remarked somewhat facetiously,

> "we met there to discuss an explosion that had occurred the day or morning before. We would all pool our heads together to figure out what went wrong, where the obstruction or the hot spot was. Then one of us would say, 'Why not try such-and-such?' "Bun," a nickname for Lawrence, would respond, 'Yeah, let's try it!' Then we would all get back and work like hell, sometimes until 9, 10 or 11 at night. Sometimes John Shesta would also come around with a clipboard and just make up modifications on-the-spot." [11].

"Our greatest problem during those years," Arata continued, "was heat transfer. Of course, regeneratively cooled systems were the only way to go; but this did not mean that all the cooling problems were solved, especially for long-duration runs."

One answer, which was far far perfect, was Pierce's idea of making a corrugated, helical winding or spiral out of a metal ribbon by running it through the loosened gear teeth of a lathe. The windings were placed between the cooling jacket and liner for swirling the fuel. The object was to slow down the circulation process so that the motor would be better cooled. The fuel was preheated for better combustion.

The difficulty with this technique was that the ribbons were not always placed in the right positions. After some faulty test runs, the motors were dismantled to learn the difficulty. Often it was found that the ribbons were jammed in such a way as to cause fuel blockage rather than to assist the flow. Sometimes, unknowingly to the RMI workmen, the ribbons shifted during the manufacture, prompting the staff to dub them derogatorily, "wiggle rings." After one or two Traingle Grill sessions, this problem, too, was overcome. The rings were replaced with wires that fitted into spiral grooves around the cooling liner. By adjusting them at different angles and lengths, it was possible to regulate the coolant flow [12].

The completed 3,000 lb (1360 kg) thrust motor weighed 75 lb (34 kg) with auxiliaries (nitrogen pressure bottle and other tanks). The chamber was about 6 in (15 cm) in diameter and 6 ft (1.8 m) long. A run conducted on 6 May 1943, according to Wyld's handwritten note in the RMI logbook cited above, lasted 24 seconds at high thrust of 3,180 lb (1442 kg) maximum. "Flame straight," Wyld observed, "not remarkably long but intensely hot – started a number of small fires in woods and scorched ground. Also

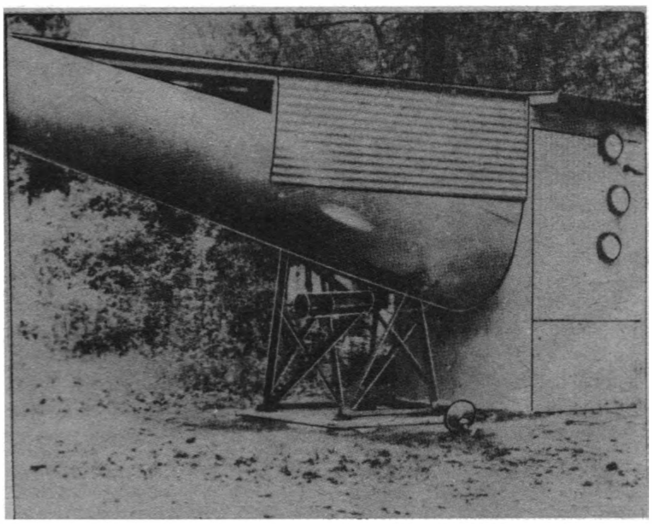

Fig. 2. RMI's 3000-A-1 on a Martin PBY aircraft tail mockup, ca. 1943.

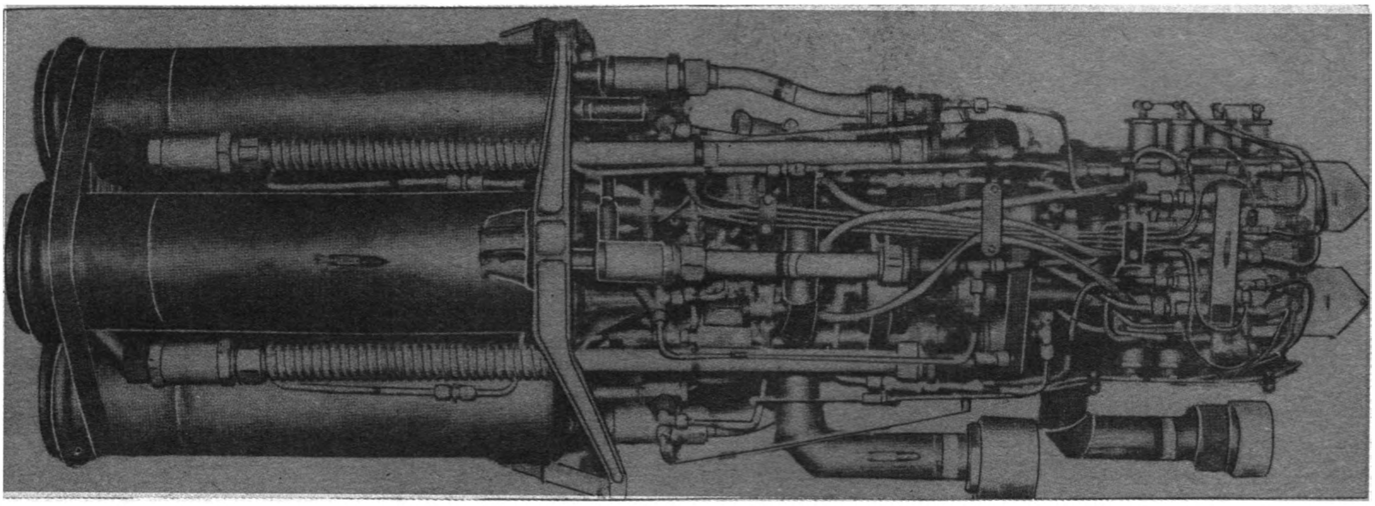

Fig. 3. RMI's 6000C4 rocket engine.

burned corners off some nearby sandbags... Motor appears to be in excellent shape after run..." (Fig. 1).

In subsequent tests, igniter problems cropped up; but on 14 May 1943, a "very long run, probably over 1 min" was recorded. This became the standard duration of the engine [13].

By October, the first static tests were made with simulated PBM-3 aircraft boattails made of plywood and covered with corrugated metal. This phase of the testing was undertaken in RMI's New Jersey plant, (Fig. 2).

Finally, the time arrived for the real tests on aircraft taking off from water. Captain William L. Gore, US Marine Corps, served as the pilot of the first RMI "live" Jato flight at Annapolis on 12 January 1944. (He was already a veteran of similar flights since he managed Goddard's Jato on a PBY in September 1942.) By all accounts, the RMI trials went well. Yet for all the RMI labours, the Navy never officially adopted any of the company's Jato units.

What had gone wrong?

In a word, it was RMI's choice of liquid oxygen and petrol. Compared with the proven efficiency and convenience of hypergolics used by Truax and Aerojet, Lox-petrol was not considered a practical alternative. The Navy was especially concerned about emergency wartime use of Jatos in which storable (non cryogenic) propellants had the edge. In the final analysis, Aerojet's solid-propellant Jatos were the most successful of all the Jato projects because they combined storability with simplicity and economy.

At the conclusion of the PBM tests, Shesta reminisced that "we had definitely given up gasoline as a propellant and switched to alcohol, which we felt much better suited for rockets." This higher performance and cooler fuel was subsequently used in the RMI's other rocket projects [14].

2. POWER FOR AIRCRAFT – ROCKET PLANES

Ironically, while the hypergolic combination (red-fuming) nitric acid and aniline possessed desirable qualities for Jato applications, it had very serious drawbacks that made it undesirable for aircraft propulsion. Rocket 'plane pilots would be exposed to great risks. Nonetheless, these weaknesses were felt to be soluble in time and the non igniter advantage of hypergolics led Aerojet to develop, by 1944, a 2,000 lb (900 kg) thrust, acid-aniline engine for the proposed Northrop XP-79 rocket-propelled, flying-wing interceptor for the Army Air Corps. This unit was called the Rotojet [15].

The plane did not materialise, and Rotojet was not fully developed; but by late 1944 two transonic aircraft projects began to evolve. One was the Navy proposal of a ground-launched, turbojet-powered aircraft. This became the Douglas D-558, which appeared in turbojet and jet plus rocket-powered models. The other project, sponsored by the Army Air Corps, was an air-launched, all-rocket powered aircraft known first as the Bell XS-1 and later the X-1 [16].

In January, 1945, the Navy's Ships Installation Branch was requested to develop a rocket powerplant using Lox and petrol for the D-558.

"At that time," according to the 1948 GALCIT survey *Jet Propulsion:*

> "no data was available for specific powerplant requirements. Accordingly, Reaction Motors, Inc. of Pompton Plains, N.J., was requested to undertake the development program on a small size powerplant. This approach was taken in order to anticipate and solve problems as soon as possible in small scale and hence save time as well as expenditures of money and equipment associated with large scale tests. Numerous problems in motor ignition and gas feed control were worked on in this manner during February, March and April of 1945. In the early part of May it was decided that the power plant should deliver between 4,500 pounds 2,040 kg and 6,000 pounds 2,720 kg thrust. Consequently, the total thrust was divided into four parts of 1,500 pounds 680 kg thrust each. By this method, the fourth motor can be added or deleted as required and the composite powerplant can be operated at any one of the immediate stages."

This four-chambered motor became famous as the 1500 144C and later the 6000C4, referring to its 6,000 lb (2700 kg) thrust (Fig. 3). It operated on Lox and alcohol/water rather than Lox-petrol.

"In cooperation with the Army Air Forces' program of transonic aircraft research," the GALCIT survey continues, "the Navy has arranged to release the first propulsive unit of the above design to the Bell Aircraft Corp." This is how the 6000C4 was started under a Navy contract yet first powered the Air Force-sponsored Bell X-1.

According to Harry W. Burdett, Jr, RMI's chief engineer on the 6000C4, the original engine's outer jacket was made of ordinary carbon steel (Shesta says it was chosen for reasons of economy). Carbon steel rusts; the engine also had copper tubing. Hence when the Air Force's Ezra Kotcher,

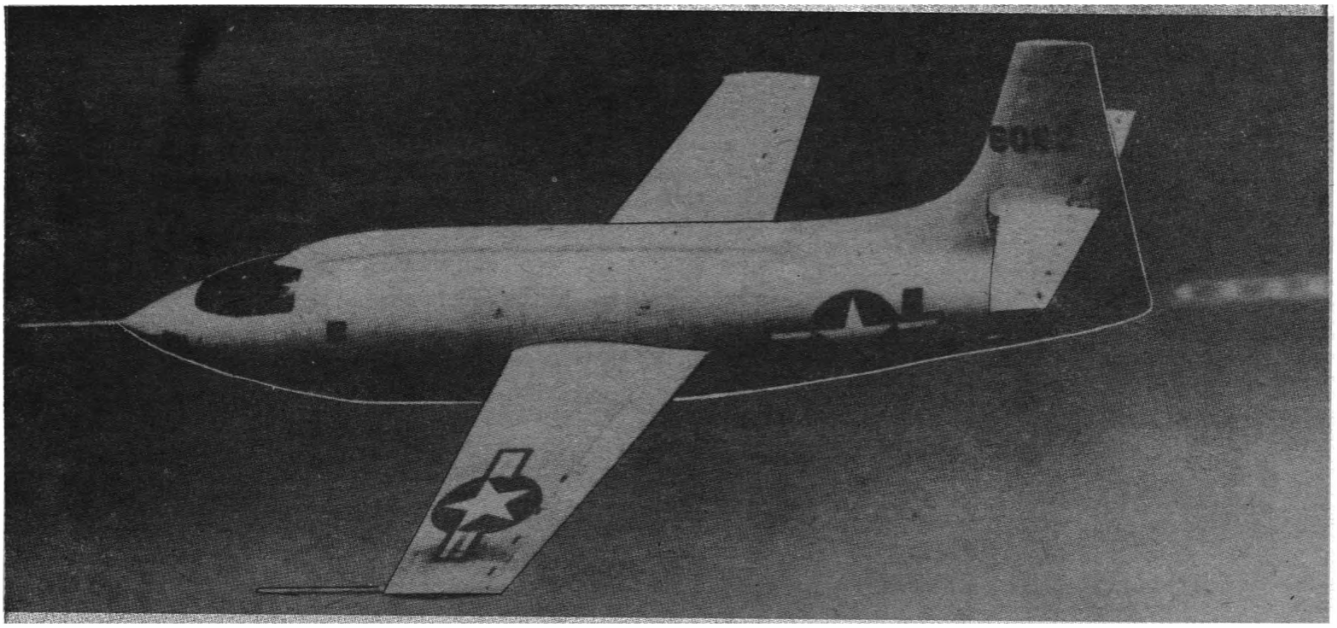

Fig. 4. Bell X-1 rocket plane making the first supersonic flight.

head of its transonic aircraft project, visited Lovell Lawrence to see if the 6000C4 could be used in the D-558, the engine was somewhat rusted and did not look presentable. Shesta recalled that the head of Bell's XS-1 design team, Robert M. Stanley, also saw the engine in this condition and remarked: "I don't like that. It's got to be stainless steel." The change was made and the engine painted black. Burdett says that because of this appearance, plus the tremendous noise it made when fired, the 6000C4 was affectionately called the "Belching Black Bastard." However, he adds, this name had to be "cleaned up for the press." Consequently, it was named "Black Betsy," after Lawrence's infant daughter, Betsy, a name that also signified reliability. Officially, the Navy designation was LR-8. The Air Force designated it the LR-11 (Liquid Rocket 11) [18].

Burdett says the first 6000C4 was fired on 30 August 1945 but that only two of the chambers worked. The other two had fuel leaks. Blowouts, ignition and injection problems were common in the development of the engine. But Lou Arata, RMI's self-taught, expert shop man adapted his own igniter which was successfully tested 500 times without failure. It was the miniature rocket similar to the scheme mentioned above. The igniter was shaped like a venturi with fuel and oxidiser inlet holes drilled in the sides. The fuel and oxidiser were premixed and ignited by a spark plug.

Lawrence, who at that time had just returned from Germany after participating in the US Government's post-war investigations of Germany's missile technology, was so impressed with the igniter that he asked Arata to immediately make four of them. The igniter, according to Arata, was the basis for the one subsequently adopted for the 6000C4 by Harry Burdett the project engineer.

Prior to passing its qualification test, the 6000C4 was subjected to more than 800 seconds total firing on RMI's specially designed test stand which simulated the roll, pitch and yaw of an aircraft. This was a large boom on which the engine could be mounted and fired in horizontal and vertical positions. Contracts C-107193 and C-108792 were awarded to Bell Aircraft, effective 29 May 1946 with a scheduled completion date of 18 April 1947 for delivery of the 6000C4. which was qualified under RMI Project No. 171 [19].

The subsequent history of RMI's 6000C4-powered aircraft, Bell XS-1 (X-1), also popularly called "Glamorous Glennis" after the pilot's wife, is well covered in the literature. On 14 October 1947, Captain Charles "Chuck" Yeager flew it and became the first man to break the sound barrier. He flew at Mach 1.06 or 700 mph (1,130 km/hr) (Fig. 4).

Other data relative to the 6000C4, which made this great advance possible, are that it burned an ethyl alcohol and water mixture with Lox. The engine was 54 in (137 cm) long and 49 in (124 cm) in diameter. (The arrangement of the four cylindrical thrust-chambers for the Air Force's X-1 was a diamond pattern; for the Navy's D-558 and other projects a square pattern was preferred.) Each chamber was 18 in (45 cm) in outside diameter. Total engine weight for the Bell X-1 version (nitrogen-fed) was 345 lb (156 kg) empty. Later 6000C4s used a feed system employing an RMI-developed turbopump driven by the decomposition of hydrogen peroxide at a speed of 12.240 rpm [20].

The 6000C4 also powered the Bell X-1A and Bell X-1-3 aircraft. With slight modifications, it was fitted in the Navy's Douglas D-558-1 Skystreak which could also be powered with an Allison J-35-A-11 5,000 lb (2,270 kg) static thrust turbojet. Similarly, Black Betsy served as the powerplant for the all-rocket Douglas D-558-2 Skyrocket and the Douglas D-558-2 Skyrocket, jet and rocket version. Some of the D-558 series were modified for air-launches. These aircraft also flew supersonic. One of the 'planes, the D-558-2 No. 2, jet and rocket version, became the world's first aircraft to exceed twice the speed of sound, reaching Mach 2.005 or 1291 mph (2,077 km/hr) during a dive on 20 November 1953; Scott Crossfield was the pilot [21].

The first rocket aircraft were experimental and designed to study transonic flight. The Air Force's Republic XF-91, fitted with a variation of the 6000C4, was the first supersonic combat fighter; though technically it was experimental. Like the Skyrocket, the XF-91 had dual powerplants. The rocket was considered an auxiliary means of propulsion for accelerated take-offs and climbs and for operations at altitudes beyond the sonic barrier. The XF-91's General Electric J-47 turbojet of 5,200 lb (2,360 kg) of static thrust provided primary power. In the XF-91, the four rocket chambers were separated, two in a vertical line above the jet engine

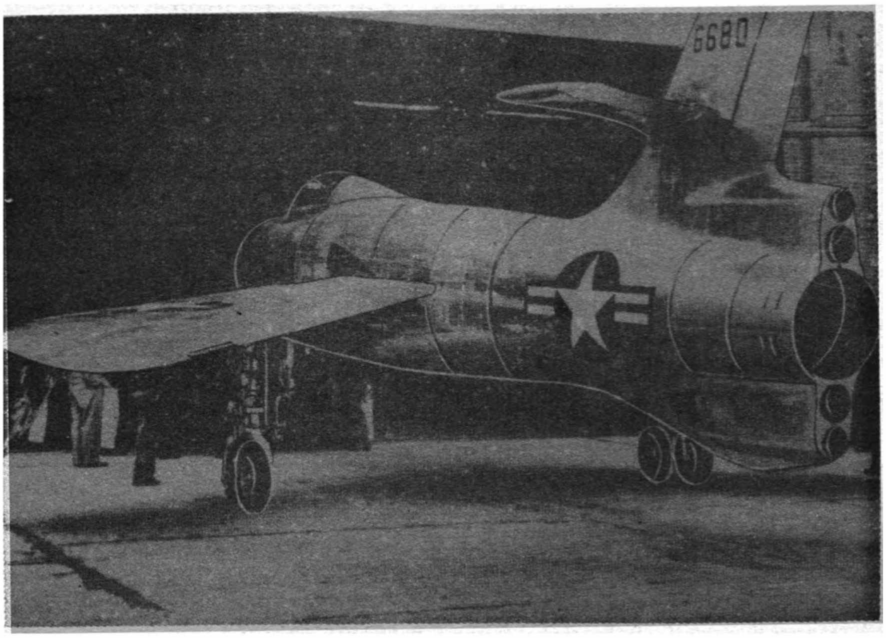

Fig. 5. Republic XF-91 jet and rocket 'plane, showing the arrangement of the jet engine and rocket units from RMI. Picture taken in February 1949 at Republic's Farmingdale, Long Island plant.

and two below (Fig. 5) [22].

In September 1952 Republic's test pilot Russell (Rusty) Roth flew the XF-91 on its first supersonic flight. The company's president, Mundy I. Peale, announced the flight shortly afterwards, stressing that the XF-91 was "not purely a research plane" and "is combat ready." Only two of the aircraft were built, however, and no production contract was let. A contemplated XF-91A with an up-rated 8,000 lb (3,630 kg) thrust rocket, possibly an Aerojet motor and a hypergolic one at that, was never built.

This was not the end of RMI's rocket powerplants. On 30 September 1955 a contract was let to North American Aviation Corporation for the development of the hypersonic X-15, which von Braun and Ordway later called "the closest thing to a winged spacecraft that has ever been built [up to 1966]." In fact, the X-15 was a major step towards the Space Shuttle.

Because of its experience and success with the earlier X-series of aircraft, RMI was awarded the contract for the X-15's engine, which became the fully throttable 59,000 lb (26,760 kg), maximum-thrust XLR99 Pioneer rocket that used anhydrous ammonia and liquid oxygen. The first flights made with the X-15, from 1959 to 1960, were accomplished (often past Mach 2) with two modified Black Betsy engines with the Air Force designation of XLR-11 [23].

3. TEST AND SOUNDING ROCKETS

Following a close second in importance to its aircraft auxiliary and principal rocket motors was a series of propulsion units developed for Navy and Air Force missile and atmospheric sounding vehicles. Included were rocket motors for the Lark surface-to-air missile test missile, the MX-774 precursor to the Atlas intercontinental ballistic missile and the Viking rocket used at first for extreme altitude exploration and later for testing components in the Vanguard satellite launch vehicle.

3.1 Lark LR2-RM-12 and XLR6-RM-4 Engines

During 1944 and 1945, RMI built approximately 50 350 lb (160 kg) thrust rocket engines that operated on mixed acid and mixed aniline hypergolic (self-igniting) propellants. Based on engineering drawings supplied by the US Naval Engineering Experiment Station of an earlier 340 lb (154 kg) CML-2N-1 design, they were mounted on the Gorgon II-A pilotless aircraft. The Navy planned on using these missiles against Japanese naval and merchant shipping during World War II.

The credit for this development is due to the Navy's Lt. William Schubert and Ensign Robertson Youngquist. According to John Shesta, "the Gorgon-Lark units were constructed by us [RMI] in accordance with their specifications. All we did was to refine some manufacturing techniques and nozzle construction." Before delivery to the Navy, each unit had first to be acceptance-tested.

The nitric acid-aniline combination was subject to ignition delay, resulting in hard starts. The problem, according to Shesta, was solved "in an elegant way" by Youngquist's pintle valve device. "The evil smelling products of combustion," Shesta recalls, "did nothing to endear us to the local population."

Building on CML-2N-1 experience, Al Huse, Edward Francisco, Ray Pepplar and other RMI engineers developed a two-chamber unit consisting of 220 lb and 400 lb (100 kg and 181 kg) thrust chambers mounted together (the latter was an uprated Gorgon II-A cylinder). Two models evolved, the pressure-fed LR2-RM-12 and the turbopump-fed XLR6 RM-4. About 500 of these engines were built for the Lark ground and ship-to-air experimental missile. The concept was to use the smaller cylinder for cruising and the larger one for extra velocity as the target was approached. Data on the two engines are summarised in Ordway and Wakeford's *International Missile 2nd Spacecraft Guide* [24] (Fig. 6).

Manufactured both by the Fairchild Engine and Airframe Company and the Consolidated Vultee Aircraft Corporation, Lark was originally designated as the XSAM-N2a. Later, in 1950, it was reclassified as the CTV-N-9 component test vehicle. Most of these were fitted with Mach limiters that permitted the missile to reach but not exceed Mach 0.85. When a Lark approached this velocity, an indicator closed the valve which, in turn, closed the propellant valve and consequently stopped the operation of the 400 lb (181 kg) thrust chamber. The reverse occurred when the missile dropped below the limiting velocity. Launchings at first took place from a 450 ft (140 m) long inclined ramp at the Naval

Ordnance Test Station, Inyokern, in California. Later, they were made from a zero-length launcher at the Naval Air Missile Test Center in Point Mugu, also in California, as well as from the USS *Norton Sound* at sea. Typically Lark would undergo 240 seconds of powered flight; but, in a test in December 1948, power lasted for 295 seconds carrying the missile over a distance of more than 25 mi (40 km).

Although the 620 lb (281 kg) thrust engines were employed exclusively for Lark, RMI felt that they could be used as assist take-off units for light liaison and command-type aircraft [24].

3.2 MX-774's XLR35-RM-1 Engine

After the war, RMI carved out a small piece of the emerging large rocket-propelled missile programmes that were based on or inspired by the V2 and other German military vehicles. During the immediate postwar period, a German team under Wernher von Braun and its American colleagues began flying and testing captured V2s from the White Sands Proving Ground in New Mexico while simultaneously embarking on the new Hermes missile project. For its part, the Navy had started developing a Viking sounding rocket that was based in considerable part on V2 technology. At the same time, the newly created Air Force was tackling a long-range rocket-powered missile using the MX-774 to test the concept.

As it turned out, RMI received engine development contracts for both the Air Force and Navy projects.

Though short-lived, the MX-774 did provide the Air Force; its airframe contractor; the Consolidated Vultee Aircraft Corporation; and RMI with valuable experience. Its motor, designated the XLR-34-RM-1, was an advanced version of the four-engine, regeneratively cooled 6000C4 engine (see Section 2) which had already been successfully flown. Feed pressure was increased to about 425 psi (30 kg/cm^2), commercial 95 per cent ethanol served as its fuel, and liquid oxygen the oxidiser. The motor operated over a nominal 7600 lb to 8,400 lb (3450 to 3800 kg) thrust range.

The mounting of the four cylinders was arranged in such a way that they could swing back and forth. Propellants were fed through two coaxial seals, one on each side of the motor, which also served as bearings. Movement was controlled by a system of hydraulic cylinders. Many difficult design problems were worked out by an RMI engineering team led by Peter Palen. Since the XLR35-RM-1 was to power an unmanned missile, it needed to be ignited only once. In the light of this, RMI engineers were able to delete the 6000C4's igniter assembly.

Extensive work was also done on the Lox face seals to permit the rotational movement of the thrust chambers on the mounting structure as well as the Lox propellant valve located in the middle of the same structure. This was undertaken by M. E. (Bud) Parker and Richard Weiss with the assistance of Frank Coss.

Shesta emphasised the importance of assuring that all the four cylinders would ignite simultaneously. If any cylinder failed to ignite while the others had successfully fired, he warned "a dangerous situation would ensue."

The ignition problem for vertically fired rockets was of special concern to him. He recalled that in the early American Rocket Society days, someone would be elected, or perhaps even volunteer, to ignite a rocket. "He would dash up... with a gasoline rag on the end of a stick, light up and run like hell. Occasionally he would be wearing an asbestos suit."

When Shesta joined the society, he refused to get involved in what he termed "foolishness."

> "We began mixing our own powder [he continued] and making squib igniters. These were started electrically. Later at RMI, Lawrence obtained a supply of meal-powder from Dupont's. This worked fine, but the combustion was too rash. There was not enough time to make sure of reliable ignition. The timing was too critical. One time I asked Jimmy Wyld to mix up a batch of powder with other things to make it burn slower and safer. He did, and he suceeded beyond our fondest hopes. It was the safest powder in the world. You could ignite it with an acetylene torch, but as soon as you pulled the torch away it would go out."

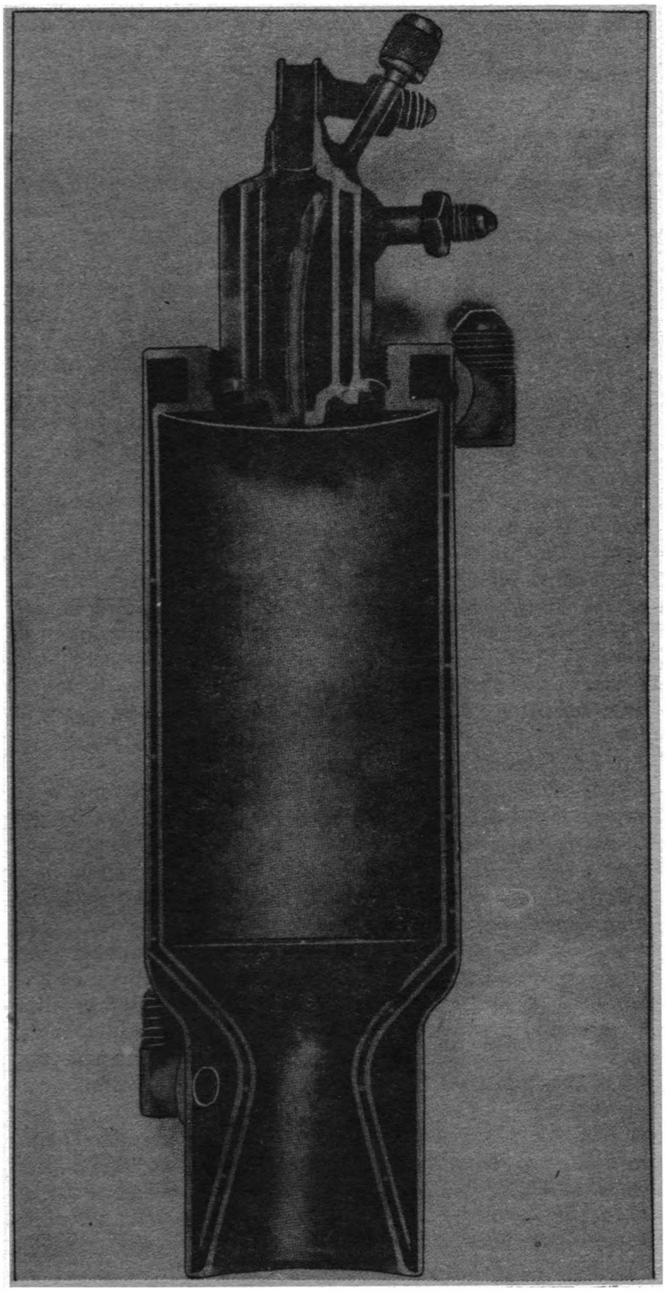

Fig. 6. The 200 lb (100 kg) thrust chamber of the 2-chamber (ML-5N rocket engine) produced for the Navy's Lark missile by RMI, 1944-45. The chamber is in the National Air and Space Museum, Washington, D.C., USA.

For the MX-774 rocket, Shesta asked Dr. Horvitz of the RMI research laboratory to come up with a good igniter. After a few experiments, he developed a composition of potassium perchlorate combined with a plastic resin which,

after being baked in the oven, resulted in hard smooth rods about 0.25 in (0.63 cm) in diameter and some 4 in (10 cm) to 6 in (15 cm) long. "These," recalled Shesta, "would burn with a fierce hot flame for about 30 seconds. In fact, they were perfect ignitors." Shesta explains how they were used:

> "One igniter cartridge was inserted in the nozzle of each cylinder. The ignition was by means of a hot (tungsten) wire 0.005 inches in diameter – the four were connected in series. A short distance beyond the ignition point, the rod was drilled and a copper wire was passed through the hole. When the fire reached the copper wire, it would melt it. These wires were connected in parallel. When all the four wires melted, they would actuate a relay, which in turn would turn on the propellants. If only three wires melted and one remained intact, nothing would happen."

The engine weighed 396 lb (180 kg). The decomposition products of hydrogen peroxide drove the turbine, which was coupled to two pumps that furnished the propellants to the combustion chambers.

The design of the XLR35-RM-1 was completed in late 1946, and model and acceptance testing was undertaken in June of the following year. A maximum thrust of 8,800 lb (4000 kg) was obtained at a specific impulse of 227 seconds. James Fitzgerald and Frank Coss of RMI took the unit through to integrated testing and then to the White Sands Proving Ground for flight testing.

The MX-774's airframe and guidance system were designed by a Convair team headed by Karel J. Bossart and consisted of three metal sections; the fuselage nose, fuselage centre and the tail. The nose section was made of aluminium alloy and housed the electrical, stabilisation, and guidance and control components, and test instrumentation. The centre section consisted entirely of propellant tankage constructed of welded aluminium. The liquid rocket engine and the control surfaces were housed in the aluminium alloy structure in the tail section. Integral tanks were introduced to rocketry with the MX-774, and separating the nosecone from the main rocket structure after peak altitude was introduced.

The MX-774 was static-tested at Point Loma, San Diego, in California, from mid-1947 to late 1948. It was flown three times at White Sands in July, September and December. A failure in the electrical system led to premature cutoff of an otherwise flawlessly functioning first flight engine. MX-774 rose over 1 mi (1.6 km) high, then crashed only 600 ft (180 m) from the blockhouse. No. 2 fared somewhat better, reaching nearly 30 mi (48 km). Excessive oxygen tank pressure caused the missile to break apart in mid-air. The third flight went well for 51 seconds when the engine cut off. An attempt was made to parachute-recover the missile, but vibrations caused it to explode. The MX-774 project is credited with demonstrating the well-known practice of steering by vectoring the rocket motors [25].

3.3 The Viking XLR10-RM-2 Engine

The engine developed for the Naval Research Laboratory's RTV-N-12 Viking high-altitude sounding rocket was quite different from that selected for the MX-774. Instead of four small thrust chambers it relied on a single, large one that produced more than 20,000 lb (9100 kg) of thrust.

The contract to develop and manufacture the XLR10-RM-2 (the official designation of the Viking rocket engine) was signed in 1946 and the first of ten engines was successfully test fired a year later. Although the early Viking launches were not impressive, in time the rocket exceeded the altitude capabilities of the captured German V2s.

The engine consisted of a large combustion chamber, a turbopump unit, and associated valves and controls. All tankage, wiring and piping were supplied by the Glenn L. Martin Company.

Over the years, improvements were made to the engine. Thus, it developed 20,450 lb (9280 kg) thrust on the first Viking flights, 21,429 lb (9720 kg) on the last. The thrust could be varied over rather wide limits by merely altering the feed pressure. It was gimbal mounted for directional control.

The thrust cylinder consisted of the combustion chamber and a venturi nozzle. It was composed of a sheet nickel inner jacket rolled into a cylinder and welded. The motor was the first to use pure nickel for both liner and nozzle. According to Robertson Youngquist, the use of nickel was chosen because of its superior conductivity (thermal) and higher melting point, the 20,000 lb (9100 kg) motor was large enough to permit fabrication from sheet stock, the only form of nickel available at the time.

The engine was cooled by circulation of the alcohol in an outer jacket surrounding the combustion chamber supported approximately a 0.25 in (0.63 cm) distance from the outside diameter of the chamber by spacer rods (that extended from one end of the chamber to the other in several short lengths). The outer jacket contour was interrupted by expansion channels which, when pressure was applied, tended to expand lengthwise to allow for thermal expansion of the combustion chamber in operation. A reinforcing ring was welded to the jacket throat section to prevent the possible distortion of the nozzle throat. The fuel entered the engine by four 1.25 in (3.2 cm) fittings at the nozzle end of the jacket and was distributed uniformly around the cylinder.

The power transmission and pumping units consisted of a single stage turbine and two centrifugal pumps. Hydrogen peroxide entered a gas generator containing a manganese dioxide catalyst. The resultant chemical reaction produced super-heated steam that was supplied to the turbine. The turbine operated at approximately 10,000 rpm and developed an output of approximately 300 hp. Impellers at both ends of the turbopump forced the propellants through the outlet ports of the pumps at the proper discharge pressures.

Among the key personnel involved in the XLR10-RM-2 engine programme, Edward A. New, Jr. was responsible for thrust chamber and injector design, Albert Thatcher for the hydrogen peroxide-driven turbopump, and M. E. Parker for valve and control work (which was borrowed in large part from the MX-774 development).

Under pressure from both the Navy and the Glenn L. Martin Co., RMI Chief Engineer William P. Munger assigned Parker – in the latter's words – "to pull it all together and get off the cold flow and hot test series." These completed, on 21 September 1948, following a prototype engine firing that produced 21,000 lb (9525 kg) of thrust for 66 seconds, the Naval Research Laboratory announced its approval. At about this time, Parker resumed his experimental project activities, and the XLR10-RM-2 production programme was continued by Delacy Ferris and Henry Jatczak. The first production engine was then shipped from RMI to Martin soon after. Meanwhile, the Viking No. 1 airframe was being fabricated there during the autumn months, and by December it had been completed. The next month, the rocket was sent from Martin's Baltimore plant to White Sands Proving Ground where preparations for static and flight firings got under way.

At the request of Milton Rosen, who directed Viking's development at the Naval Research Laboratory, Parker was sent out to White Sands Proving Ground for the first launch, which was to be preceded by a 30-second firing on the launch pad.

After a dry run on 28 February 1949, the first static test took place on 11 March, following several postponements.

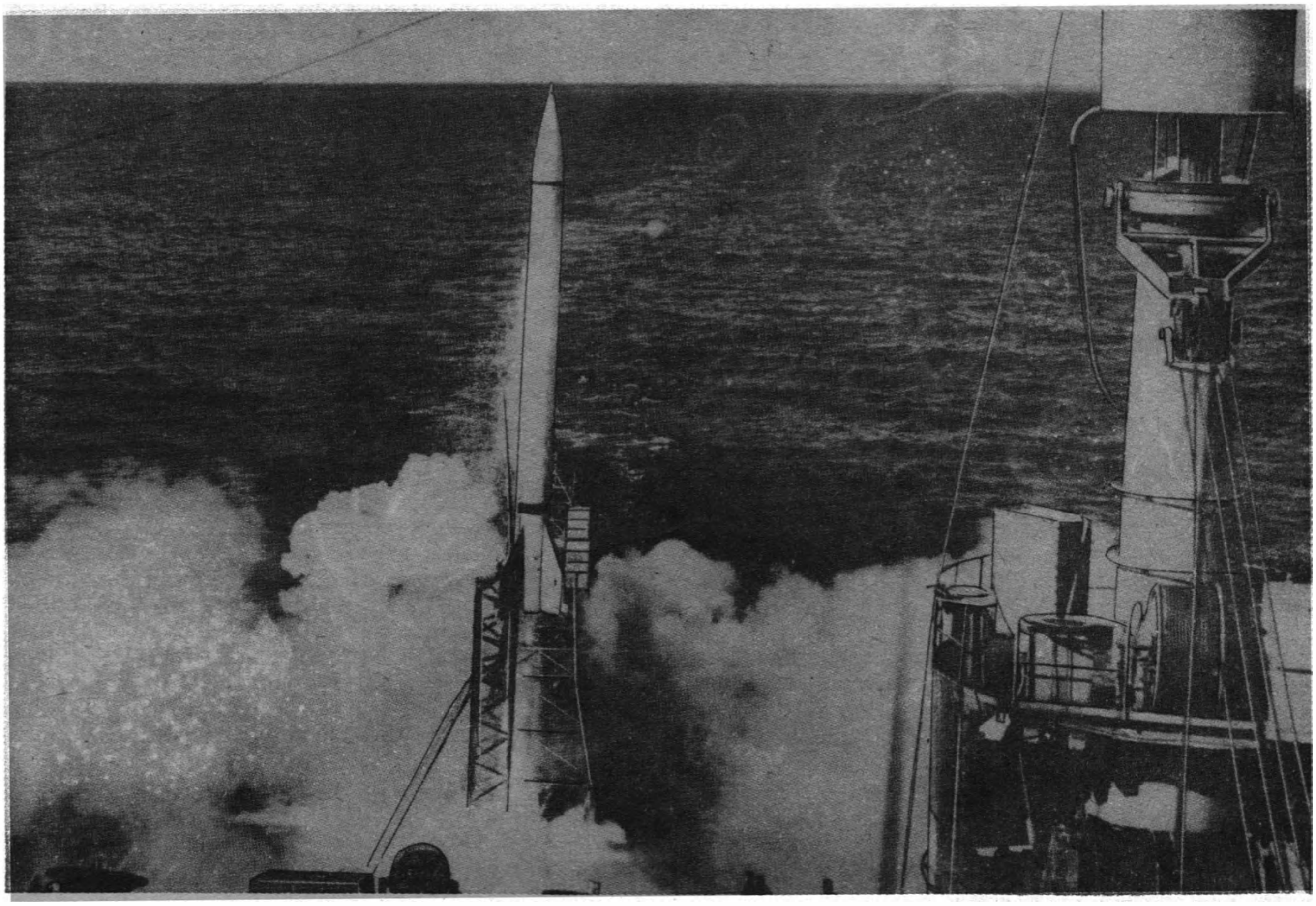

Fig. 7. Viking no. 4 is fired from the deck of the USS *Norton Sound* on 11 May 1950, carrying instruments for cosmic ray research.

Steam from the turbine exhaust started a fire in the tail section's pipe insulation, but the rocket was not damaged.

After the fire that occurred during the static test, Parker, John Cray, and the RMI crew worked night and day along with Youngquist, and the Martin crew in an attempt to eliminate the steam leak by tightening the bolts on the turbine and housing. They claimed success and that the gasket was intact. Rosen insisted on another static test to demonstrate engine integrity before he would allow the launch to proceed. But Parker and J. Preston Layton from Martin, confident that it was not necessary, refused the test, preferring that the rocket came down for disassembly and inspection. Weeks later, inspection at disassembly reavealed that the on-pad repairs by RMI had successfully accomplished what Parker and Layton had anticipated.

The second static test after reassembly and erection on the pad took place on 28 April 1949. Testing was terminated prematurely when someone thought he saw smoke. However, inspection revealed no evidence of fire.

Preparations continued, and on 3 May 1949 at 0900 hours, the Viking made its maiden flight. Launch was successful and the rocket reached an altitude of slightly more than 50 mi (80 km), 163 seconds after launch. All agreed that it was a highly creditable performance for the first flight of any rocket. It fell to Earth about 10 mi (16 km) from its launch point, having stayed aloft some six minutes. American high-altitude sounding had come of age.

Since the experience of early flights was applied to the design of later models, no two Viking were exactly alike. Flights 2 and 3, which took place in September 1949 and February 1950, reached approximately the same altitude as the first. Viking 4 was fired on 11 May 1950 from the USS *Norton Sound* in the Pacific Ocean. The test gave new information about the problems of launching rockets at sea and allowed scientists to gather data on cosmic rays in the upper atmosphere at the geomagnetic equator. Despite the difficulties of a shipboard launch, the Project Reach (as the operation was called) rocket soared to a height of 106 mi (170 km), very nearly the theoretic maximum of that particular vehicle.

The next three flights were made from White Sands Proving Ground. Viking 5 reached an altitude of 108 mi (174 km) in November 1950. The following month, Viking 6 reached only 4 mi (6 km) because of a rapid deterioration of aerodynamic stability after fin control was lost. Viking 7, flown in August 1951, established a record height of 136 mi (219 km). All three carried instruments that included Geiger counters, ionisation chambers, photomultiplier tubes and cameras.

More than a year went by before the next firing. The time was used to carry on design work, in process since 1950, for a larger, heavier Viking with a motor capable of firing for more than 100 seconds (compared to the 50 to 80 seconds of the earlier models). Almost all the extra 3,500 lb (1600 kg) weight going into the new Vikings was propellant, not structure. The modified rocket could go higher than the old Vikings or carry heavier payloads to the same altitude.

Seven of the new Vikings and their rocket engines were built and flown. The only failure was the first one, Viking 8, which experienced one of the most unusual accidents in rocket history. During static testing on the morning of 6 June 1952, it broke loose from the test stand, flew 4 mi (6 km) up, and crashed on the desert 5 mi (8 km) away. Scientists and engineers on the scene could hardly believe

their eyes as the rocket rose into the air. On future models, four tie-down points rather than two were used and the rocket tail section was strengthened.

The remaining six Vikings were fired between 15 December 1952 and 1 May 1957. Viking 11 distinguished itself in May 1954 by soaring to a new record height of 158 mi (254 km) with 852 lb (286 kg) of instruments aboard. Its RMI rocket engine fired for 103 seconds and brought the vehicle to a velocity of 4,300 mi/h (1691 km/h), also a record for the series.

Viking 12 was, in many ways, the last true member of the family. It reached a height of 144 mi (232 km) on 4 February 1955. The last two Vikings were fired, not for high-altitude research, but to check out components for the forthcoming Vanguard space carrier vehicle. They were flown from Cape Canaveral, Florida, rather than White Sands Proving Ground. Milton W. Rosen's *The Viking Rocket Story*, and several works by Homer E. Newell, Jr. cited in the bibliography summarise all 14 Viking flights.

Homer E. Newell, Jr. was head of the Naval Research Laboratory's Rocket Sonde Research Section. Looking back upon Viking from the perspective of several decades, he had this to say about the programme in his *Beyond the Atmosphere*:

> ...the Viking, although of a marvelous design... found very little use. The dozen rockets bought for the development program were, of course, instrumented for high-altitude research. But Viking was too expensive. The groups engaged in rocket sounding each had perhaps a few hundred thousand dollars a year to expend on the research and a single Viking would have eaten up the whole budget... It had been hoped that Viking would be much less expensive, but before the end of the development these rockets became almost as expensive as new V2s. So Viking found no takers among the atmospheric sounding groups and would probably have been shelved had it not been chosen as the starting point for the Vanguard IGY [International Geophysical Year] satellite launching vehicle [26].

His assessment may not be entirely fair. True, Viking was an expensive vehicle, but it allowed valuable research on the nature of upper atmospheric phenomena. Even more important, however much it may have owed to imported V2 technology, Viking was an *American* project that provided vital experience to a growing cadre of American rocket scientists and technicians. This experience would prove its worth in the years to come – for RMI, Glenn L. Martin Company and the Navy.

4. OTHER IMPORTANT TECHNICAL DEVELOPMENTS

The RMI story would hardly be complete without briefly relating some pioneering development work that made major inroads in the state-of-the-art that have lasted to the present. These developments are represented by the:

1949-1951 XLR22-RM-2: Bleed Turbine Turbo Rocket, 5000 lb (2270 kg) thrust, using liquid ammonia/Lox.

1950-1951 XLR26-RM-2: Topping Turbine Turbo Rocket, 5000 lb (2270 kg) thrust, using white fuming nitric acid and kerosene.

1951-1953 XLR30-RM-2: Super Viking Rocket, 50,000 lb (22,700 kg) thrust, using liquid ammonia and Lox.

These engines were Navy-sponsored experimental developments that never reached application stage but which demonstrated highly integrated engines of extremely low weight. They operated at high chamber pressures, high turbine speeds and utilised advanced engine cycles. The topping turbine, in fact, had the regeneratively-cooled turbine blades located just forward of the throat in the main thrust chamber.

The bleed chamber turbine drew gases from the main chamber and diluted them with fuel to bring the temperature down to 1200°C for the turbine drive. The bleed turbine experimental work led to the development of components for the XLR30 Super Viking engine – this engine was converted later to the LR99 for the X-15.

A most important development during this period was the "Spaghetti" construction, as it was dubbed by its inventor, Edward A. Neu, Jr. This concept, upon which Neu applied for a patent in 1947, used tubes preformed in such a way that when properly bundled they formed the shape of the combustion chamber. The longitudinally-placed tubes welded together thus served the dual function of being the chamber itself and the coolant passages. This chamber was also very lightweight yet strong.

The concept, now taken for granted, was the first tried on a nozzle section of an RMI 400 lb (180 kg) thrust chamber. The tubes were of copper and joined by silver solder. Lou Arata made the first one himself, including the die that formed the tubes into the proper profile. Bud Parker, then running the company's experimental project group, was impressed by the idea and with help from Neu and Arata, applied it to both the XLR22 (with Bob Cramer leading the effort) and the XLR26 (with Neil O'Rourke as the project engineer).

During this early phase of the "Spaghetti" technique development, the tubing used ran a gamut of possibilities – including copper, nickel, stainless steel (347), inconel, aluminium and carbon steel. Thrust chambers of each of these metals were fired successfully. Methods of joining the tubes varied from soft solder, silver solder, welding and furnace brazing. All of these methods were also found to be successful, with furnace brazing considered the optimum. It was later incorporated into the X-15's LR99 engine.

The "Spaghetti" technique found its way into all the engines mentioned above, the XLR22-RM-2, XLR26-RM-2 and XLR30-RM-2. This method of construction soon spread throughout the industry by the mid-1950's, for example: Rocketdyne with its Jupiter and Atlas engines and Aerojet with its Titan engines. Eventually, all of Rocketdyne's powerplants for the Saturn series used some variation of Ed Neu's tubular construction.

Today, the Space Shuttle's main engines are built upon this concept and also utilise an engine cycle related to the topping system that RMI pioneered during 1950-1951.

Credit must be given here too to RMI's chemistry laboratory, founded in 1946 and guided until 1953 by the Austrian-born chemist Dr. Paul F. Winternitz. Winternitz conducted an extensive propellant research programme and was responsible for perfecting the liquid ammonia-Lox combination which, as noted above, powered the XLR22-RM-2, the XLR30-RM-2 and, later, the X-15's LR99. Winternitz probably made the first performance calculations on the boranes as rocket fuel from 1947 and he also studied ethylene oxide as a monopropellant and other exotic high-energy mixtures. (Interestingly, Winternitz's experience with Lox went back to pre-World War I when he was a research chemist with the Linde Corporation in Bavaria; during 1915-1919, as a lieutenant in the Austrian Army, he worked on explosives, especially those using Lox.) [27].

5. MISCELLANEOUS PROJECTS

Throughout its existence RMI proved its innovativeness.

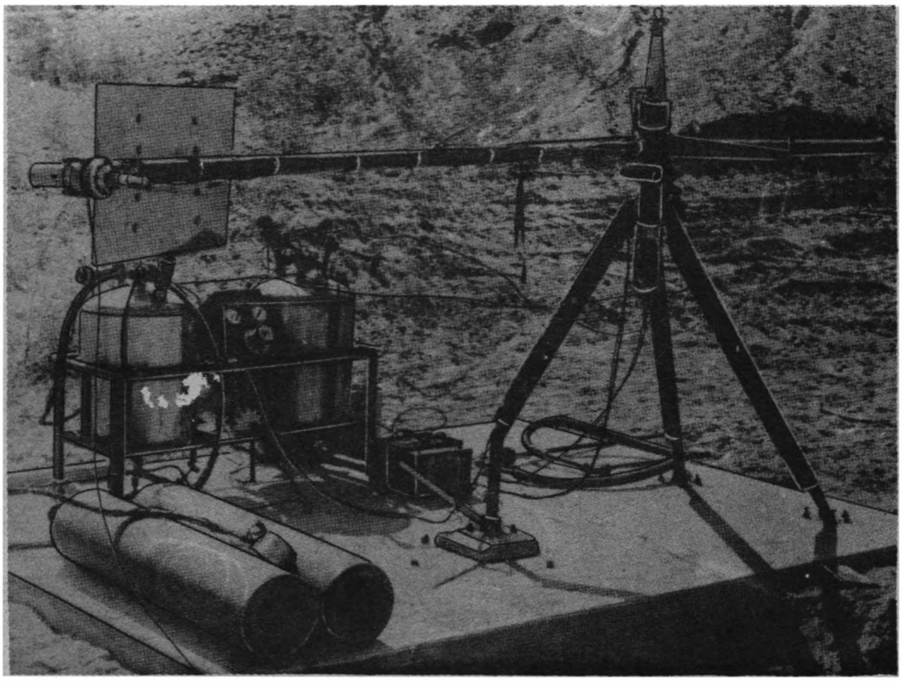

Fig. 8. An early attempt to make a rocket powered helicopter was begun in 1944 by Franklin Pierce, in which two 50 lb (22 kg) thrust Lox and petrol rockets were secured to the ends of the rotating tubes simulating helicopter blades. There was too much leakage of Lox from the rockets.

Apart from projects such as Jatos, the famous 6000C4 and the Viking powerplants, RMI also undertook several smaller but no less important endeavours.

The RMI logbook cited above reports a moment of inertia test on 1 May 1944 with a 60 lb (27 kg) autogiro blade. According to Lou Arata, this started out as Pierce's project. Shesta recalled the blade came from Pitcairn Aviation Inc. and was in an attempt to test the feasbility of a liquid-propellant, rocket-powered helicopter (Fig. 8). Chuck Towns managed the programme.

For the purpose, said Arata, an A-frame was secured to a concrete slab. The rotating mechanism was affixed in the middle with a 2 in (5 cm) diameter tube protruding from it. This tube simulated the blade for the combustion tests. Two 50 lb (22 kg) Lox/petrol regeneratively cooled rockets were attached to each end of the tube. The fuel and oxidiser feed lines led down the tube to the centre and led from their respective tanks.

The blade worked – after a fashion. It rotated as it should have done, but Arata and Shesta said there was a great leakage of Lox. The Lox also evaporated and the feed was intermittent. The project was abandoned soon afterwards though it may have been the first attempt to build a liquid-propellant rocket helicopter. The experiment anticipated RMI's Rocket-On-Rotor (ROR) project of 1954, which was much more successful [28].

In July 1944, Shesta recalled, "our engineers were summoned to the [Navy's] Bureau of Aeronautics in Washington for consultation in connection with the German V-1." "At the same time," he continued:

> "certain sketchy details of the construction of the powerplant were relayed to us and we were requested to construct and test a duplicate thereof. Work on this project was started in the middle of July and was completed on or about the first week in August 1944. These tests continued to about the middle of September 1944, at which time we took the motor to the Philadelphia Naval Aircraft Factory in Philadelphia, for further testing."

The RMI logbook reports one static test at the New Jersey plant on 15 September 1944:

> "Made 5 test starts without German reg. [ulator]... Ran as long as air was injected. Put in reg. made 3 test starts. #3 kept unit firing without air injection. After about 30 sec. [onds] the impulsing smoothed out and increased in intensity."

The V1 engine was an air-breathing pulsejet, not a rocket; but it did fit the mission of the company: the development of reaction motors. The 1946 GALCIT survey *Jet Propulsion* noted RMI's little-known contributions in this unique area of reaction propulsion. RMI "successfully modified the V-1's aeroresonator to extend the valve life to approximately four times that [of] the German valve," the survey reported. The company "has practically completed development of an air-fuel intake system which will greatly reduce the drag of the propulsion device and increase the efficiency," it added.

Arata made a V1 pulsejet during the course of this research; and initial tests were also made with scaled-down versions subjected to wind-tunnel tests that used an antiquated aircraft engine for ramming in the air. In other tests, simulated air was fed from tanks containing 21% oxygen and 79% nitrogen. John Shesta briefly summed up the purpose for this interesting departure from RMI's rocket work. The Navy, he said, were exploring the possibilities of producing its own pilotless V1 missile. The pulsejet-powered Navy Loon missile did emerge following World War II, but the motor was manufactured by the Ford Motor Company [29].

Another unusual RMI project was a rocket-driven boat. G. Edward Pendray, in his book *The Coming Age of Rocket Power* (1945), states that this vessel was tested during February and March 1944 for several purposes, including the delivery of mail from ship-to-shore, rescue work, and "for sport events." Wartime restrictions apparently did not permit the RMI founders and former fellow members of the American Rocket Society to reveal to Pendray the primary

Fig. 9. Experimental rocket-propelled landing craft using a standard 250 lb (113 kg) thrust liquid Jato, preparing for test on the Severn River near Annapolis during February-March 1944. H. F. Pierce appears to be on the right (cigarette in mouth).

purpose of the boat: to act as a very fast beach landing craft in the projected invasion of Japan (Fig. 9).

Pendray did say that the boat was powered by a standard RMI 250 lb (113 kg) thrust motor using Lox and petrol. Lou Arata believed that it was one of the Lark missile engines, although the Larks employed nitric acid and aniline. Since John Shesta remembered that the boat's rocket engine "burned a very long time, about five minutes," it could well have been a Lark sustainer that ran for 260 seconds. Pendray may not have been informed of the hypergolic acid-analine fuel and was only personally acquainted with Lox and petrol, which powered all the ARS engines. At any rate, Franklin Pierce made several experimental runs of the boat on the Severn River, near Annapolis, clearly indicating Navy interest in the project. Speeds up to 40 mph (64 km/hr) were attained with "no problem;" but steering was found to be extremely difficult especially at higher speeds. Nothing further was heard of the curious rocket boat, which never reached full development stage [30].

On a spare-time, "for fun only" basis, RMI Chief Test Supervisor Ernest John "Buck" Pellington, a former World War II B-24 crew chief with 58 missions over Germany, supervised the design and construction of a stainless steel tubing rocket-propelled ice sled. Fitted with a 400 lb (180 kg) thrust Lox and alcohol engine, the 1,648 lb (747 kg), 16 ft (4.8 m) long sled attained a top speed of 90 mph (152 km/hr) in its initial test run on frozen Lake Hopatcong near the RMI plant at Dover, New Jersey. Pellington encountered rough ice and steering difficulties and had to shut down the engine after 18 seconds. Otherwise, greater velocities for the streamlined, aircraft-like sled would have been possible. The Austrian Max Valier and the American Harry Bull made and rode rocket sleds in 1929 and 1931, respectively, but this was the first liquid-propellant type [31].

RMI became involved with another rocket-powered helicopter in 1951. The firm made the 16F1 hydrogen peroxide engines (16 lb, 7 kg thrust) for the tiny 100 lb (45 kg), two-bladed, strap-on helicopter invented by Gilbert Magill. Magill manufactured the machine on an experimental basis under an Office of Naval Research contract through his Rotor-Craft Corporation of Glendale, California. The rockets were attached to each blade. The helicopter, known as the Rotorcraft RH-1 Project Pinwheel, was strapped to a man's back and waist with the man resting on a bicycle seat (Fig. 10). The military implications of Magill's invention were many and included soldiers leap-frogging over entire armies, climbing inacccessable terrain, etc. In effect, this was one of the first so-called "jet packs," though Magill's project seems to have been short-lived [32].

A more bonafide rocket helicopter was RMI's (Rocket-On-Rotor) produced in 1954, though preliminary work was begun in 1951, perhaps as a follow-on to the Magill Pinwheel. It consisted of small XLR32-RM-2 40 lb (18 kg) thrust hydrogen peroxide motors mounted on the three blade tips of a full-sized helicopter, the Sikorsky HRS-2 (S-55 type) of the US Marine Corps. The system weighed 67 lb (30 kg) dry yet could increase a helicopter's lifting potential by 20%; which was a great advantage in wartime situations. A dome-shaped tank above the rotor hub carried enough fuel for six minutes, or 20-25 take-offs. Tests covered 1,000 starts and stops with helicopters of the Marine Experimental Squadron HMX-1 at Quantico, Virginia. A 99.5% reliability record was achieved. Faster take-offs, high altitude, and improved rates of climb and hovering ceiling were also advantages of the ROR; yet the system did not become operational [33].

Apart from these miscellaneous projects, RMI was involved with many other, often fruitful lines of research during this pioneering period. For example, from 1946 the company initiated the development of gas-generators for aircraft catapults using the rocket principle. This system, called ICCP (Internal Combustion Catapult Powerplant), was conducted under a Navy contract. Rocket-ramjet studies

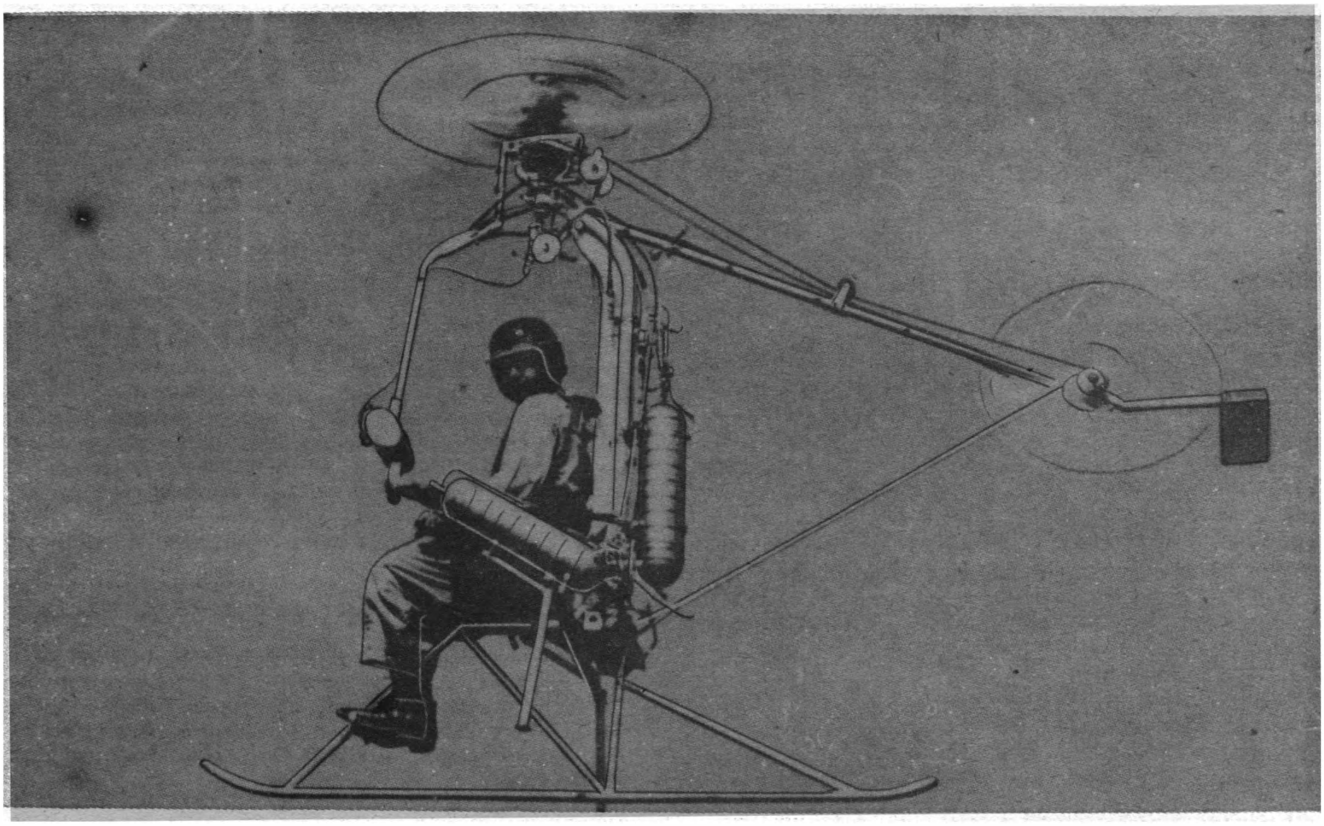

Fig. 10. Rotorcraft RN-1 "Pinwheel" helicopter with RMI's 16F1 hydrogen peroxide 16 lb (7 kg) thrust rocket engine on the rotor tips, Glendale, California, ca. 1951.

were undertaken from 1946. The X50-API Auxiliary Power Pack, designed under an Air Force contract to produce auxiliary turbine power operating independently of the atmosphere, was developed from 1950. A solid propellant gas generator for tank pressurisation was manufactured in 1951. In the same year, RMI evaluated ceramics for thrust chambers, gas generators and igniters. A more exotic project was the rocket for drilling into the ground, a rocket-age version of the pneumatic drill that appeared in 1951. Boundary layer control air-pumping systems studies were made for the Chase and Cessna Aircraft companies in 1952 [34].

In 1954, the US Air Force conducted a competition for a second source of the Atlas missile's three-engine principal propulsion system under development by Rocketdyne. The competition was important, for it was widely believed at the time that there was room for only two contractors in the business of developing and manufacturing very large liquid-propellant rocket engines. By virtue of its contract for the Atlas missile, Rocketdyne was one of these.

Reaction Motors and Aerojet went all out to become the second beneficiary of the eagerly sought contract. RMI designed and built a full-scale motor with a nominal thrust of 185,000 lb (83,900 kg) using spaghetti construction along with a prototype full-scale, two-stage turbopump to give the company a head start in the event it were to win the competition. Meanwhile, Aerojet focussed its efforts and money principally on new test facilities in Sacramento, California. As it turned out, Aerojet won the competition with the understanding that they would subcontract an important portion of the Air Force work to Reaction Motors – RMI's proposal though weak in the facilities area was strong technically.

Thus, RMI found itself devoting an increasing effort in supporting Aerojet ICBM work. As time progressed, RMI specialised more and more in vernier engine technology, important to the Atlas ICBM configuration. "Small engines they may have been," observed Bud Parker, "but at least they represented a discreet package" [35]. But problems arose: though Aerojet clearly wanted to take advantage of Reaction Motors' know-how and technology, it also began to explore ways of eliminating RMI as a competitor. In this, it was at least partially successful.

In the mid-1950s, the Air Force established a requirement for a backup ICBM to the Atlas. Aerojet's responsibilities soon encompassed the primary propulsion for this missile – and Titan, unlike Atlas, did not incorporate vernier engines. Recognising the spot RMI was clearly in, management immediately began to seek new work divorced from the ICBM programme. By the time Titan became an approved project in January 1957, RMI was out of the ICBM game.

Reaction Motors had moved swiftly, and during 1956 a number of other programmes came into being. One was known as ARA for Advanced Research Airplane, the beginning of the development of the XLR-99 for the X-15. Another was the development of the XLR-44, an integrated packaged liquid propellant engine for the Sparrow air-to-air missile. It grew out of the RMI "Can Do" project, a company-sponsored effort during 1953 and 1954 to demonstrate the feasibility of this packaged liquid engine using solid-propellant tank pressurisation. The XLR-44 was brought through the development cycle and became fully qualified during the 1957-1958 period. Production was limited, however, and the packaged liquid version of the Sparrow missile was never made operational. However, during the same period the LR-58 Bullpup engine was successfully developed and qualified, and went into large-scale production. This project will be discussed in the third part of this series on the Reaction Motors Division of Thiokol.

Still another area probed by Reaction Motors during the final years of its independent existence was the Super P, a development programme calling for a hydrogen peroxide oxidiser/JP4 fuel turborocket. Designated XCR-40, it was to be employed in a high-performance Navy fighter aircraft. Super P was a highly integrated, light-weight unit using an aluminium spaghetti combustion chamber. The engine was fully developed and had approached the final stage for delivery to the customer, Chance Vought, when an unfortunate accident in an RMI test stand killed one of their employees. Safety concerns led to major redesigns of the turbopump. In the end, delays brought on by the redesign effort effectively killed the programme.

Other activities include a 500,000 lb (nearly 227,000 kg) thrust JP4 fuel, hydrogen peroxide oxidiser pressured rocket engine for a US Air Force supersonic sled. It was, however, cancelled after engine design was completed. Through 1957, the company was engaged on the Corvus, a US Navy-sponsored, Temco-built missile programme that resulted in a development contract for the XCR-48 turbo-rocket engine; it operated on IRFNA and MAF (mixed amine fuel) propellant (hydrazine). The programme proceeded through engine qualification. Another effort was the development of a 35,000 lb (15,870 kg) thrust test stand unit for the Army Ballistic Missile Agency's nosecone test activities. The unit was designated 164-MHG Burner.

Finally, during the 1953-1957 period, Reaction Motors carried on some solid propellant research and development. According to Parker, "a very significant solid propellant research group was established and this group became well-known in their efforts to leap frog into the advanced, high-performance solid propellant area" [35]. RMI's solid activities were closely coordinated with the Olin Mathieson Chemical Corporation, and were rather successful in pursuing contracts with the Air Force. Some work went on in the hybrid propellant area as well.

REFERENCES AND NOTES

1. Letter, T. J. Bennett, in *Flight,* 26 March 1910, p. 244.
2. U.S. Patent 1,003, 411 of 19 September 1911 to H. H. Bales; British Patent 229, 670 of 19 February 1924 to A. Lepinte; and V. I. Dudakov, "Analysis of the Early Period of Using JATO in Aviation" (in Russian), *Proceedings of the 13th International Congress of the History of Science,* Moscow, 18-24 August 1971, pp. 44-46.
3. I. Essers, *Max Valier. A Pioneer of Space Travel* (National Aeronautics and Space Administration: Washington, D.C. 1976).
4. "Jato" file, National Air and Space Museum.
5. Interview with Lou Arata by Winter, 9 June 1982; interview with George S. James by Winter, 8 June 1982; and interview with Robert C. Truax by Winter, 7 June 1982.
6. Esther C. Goddard and G. Edward Pendray, eds., *The Papers of Robert H. Goddard* (McGraw-Hill: New York, 1970), Vol. III, pp. 1478, 1558-1560, 1572-1573.
7. F. J. Malina, "The U.S. Army Air Corps Jet Propulsion Research Project, GALCIT Project No. 1, 1939-1946: A Memoir" in R. Cargill Hall, ed., *Essays on the History Symposia of the International Academy of Astronautics, 1977* (NASA Conference Publication 2014), II, pp. 167-168.
8. Interviews with John Shesta by Winter, 10 June 1982, and by Ordway, 3-6 July 1982.
9. Reaction Motors, Inc., handwritten (pencil) logbook by James H. Wyld, *et al.,* 1943-1945, donated to the National Air and Space Museum by John Shesta; Shesta interviews; and U.S. Patent 2,479,888 of 23 August 1949 to James H. Wyld and Lovell Lawrence.
10. RMI Logbook and Arata interview.
11. Arata interview and Shesta interviews.
12. Arata interview.
13. RMI Logbook.
14. C. W. Schnare, "Development of ATO and Engines for Manned Rocket Aircraft," American Rocket Society Paper 2088-61; and Shesta interviews.
15. James interview.
16. Richard P. Hallion, *Supersonic Flight* (Macmillan Co.: New York, 1972), pp. 20-21 and 39-40.
17. Guggenheim Aeronautical Laboratory, GALCIT, California Institute of Technology survey, *Jet Propulsion* (California Institute of Technology: Pasadena, California, 1946), pp. 136-137.
18. Interview with Harry W. Burdett, Jr. by Winter, 25 June 1982.
19. Burdett interview; Arata interview; Reaction Motors, Inc., untitled, unpublished list of RMI projects and project numbers with dates, 1946-1955, in "Reaction Motors, Inc." file, National Air and Space Museum.
20. Reaction Motors, Inc., *Liquid Propellant Rocket Engines Developed for the US Military Services.* Formerly a Confidential Handbook, looseleaf, ca. 1952.
21. *Op. cit,* Hallion, pp. 203-205, 172-173.
22. "Rocket-Powered Fighter Breaks the Sound Barrier," *New York Times,* 10 December 1952; and Albert M. Skea, "New Fighter Plane Fast," *Evening News* (Newark, New Jersey), 10 December 1952.
23. *Ibid;* and Eugene M. Emme, ed., *Aeronautics and Astronautics 1915-60* (U.S. Government Printing Office: Washington, D.C. 1961), p. 79.
24. Shesta interviews; and Frederick I. Ordway, III and Ronald C. Wakeford, *International Missile and Spacecraft Guide* (McGraw-Hill: New York, 1960), pp. 187-188.
25. MX-774 file, National Air and Space Museum; RMI files, Alabama Space and Rocket Center; and Shesta and Parker interviews by Ordway.
26. Milton W. Rosen, *The Viking Rocket Story* (Harper and Brothers: New York, 1953), passim; Milton W. Rosen, "The Viking Rocket: Memoir," paper presented at the 6th International Astronautical Federation History Symposium, Vienna, October 1972; Homer E. Newell, Jr., *High Altitude Rocket Research* (Academic Press: New York, 1954), passim; Homer E. Newell Jr., *Beyond the Atmosphere* (National Aeronautics and Space Administration: Washington, D.C. 1980), p. 58; and interviews with Robertson Youngquist by Ordway, 27 August and 29 December 1982.
27. Typed M. E. (Bud) Parker notes, n.d. in "Reaction Motors, Inc." file, National Air and Space Museum.
28. RMI Logbbok; and Arata interview.
29. *Ibid;* and John Shesta, untitled document unpublished in the RMI archives, Thiokol Corp., Newtown, Pennsylvania (now Morton-Thiokol, Chicago, Illinois).
30. G. Edward Pendray, *The Coming Age of Rocket Power* (Harper and Brothers: New York, 1945), pp. 171-172.
31. "Rocket Propelled Boat Tested at Lake Hopatcong," *Morristown Daily Record* (Morristown, New Jersey), 3 March 1947; and "Midvale Vet Hopes to Get Jet-Iceboat Up to 200 MPH," Midvale, New Jersey, paper unknown, March 1947, from "Reaction Motors, Inc." file, National Air and Space Museum.
32. "Tiny Rocket Helicopter Tested Here," *Los Angeles News,* 23 October 1951.
33. "Marines Visit RMI Employees, Show Off ROR," RMI *Rocket,* 7 March 1956, pp. 1, 8; "Tiny New Rocket Engine Boost Payload for Copters," *Aviation Week,* 27 September 1954, p. 17; and "Rocket Assistance for Helicopters," *Flight,* 66, 24 September 1954, p. 500.
34. Interview with M. E. (Bud) Parker by Ordway, Huntsville, Alabama, 26 March 1982 and subsequent conversations, and letter from same, 27 July 1982; Shesta interviews and Youngguist interviews.
35. Interview with M. E. (Bud) Parker by Ordway, Huntsville, Alabama, 31 August 1984 and letter from same with notes, 20 September 1984.

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A STUDY OF EARLY KOREAN ROCKETS (1377-1600)*

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The first Korean rocket was fired between 1377 and 1389 and began the Korean development of rockets as a tactical weapon. Although Korea had successfully demonstrated the use of rockets as firearms in the fifteenth century, there has been no effort to present the historical development of the early Korean rockets in a paper that will be useful to both historians and scientists. The book entitled *Kuk Cho Ore Sorye* (1474), in the Korean language, provided extensive descriptions of rocket systems; but it required considerable research to interpret them. This paper was the first study of early Korean rockets and launchers. The major effort in this study is directed toward the development of the design concepts and details of early Korean rockets. Also, to substantiate support the historical data presented, some versions of the early Korean rockets and other firearms, specifically cannon, rifles and bombs, were made according to their specifications; some of the firearms were fired successfully by the author in 1981.

1. INTRODUCTION

This is the first modern study of ancient Korean rockets. In this paper the detailed structure of the invention and development of early rockets and rocket launchers in Korea are decsribed.

Modern working drawings were made from the ancient descriptions, and were used to construct and fire modern versions of the ancient weapons [1].

The oldest book in the field of firearms in Korea is *Kuk Cho Ore Sorye*, published in 1474. The chapter "Firearms Illustration" [2] contains figures and very detailed descriptions of 23 kinds of firearms that were developed between 1448 and 1452, excluding a description of the process of manufacturing black powder in Korea. "The Introduction and Development of Firearms in Korea (1356-1474)" was written by Ho, Son-Do [3], who has been studying Korean ancient firearms since early 1960. He has written several papers on Korean firearms generally, except the rocket-propelled arrows [4]. He used mainly the *Cho Son Wang Cho Silok* [5] for his study, which is an important source of history of Korean firearms. Other papers on Korean firearms are those by Jeon [6] and Boots [7].

Ancient Korean rockets have received little attention even though Koreans have used gun powder since 1377 and have made many kinds of firearms for several hundred years [8].

The first black powder in Korea was made by Choi, Mu-Son in 1377. During the third year of Shin Yu (1377), the office of a Hwa-tong-do-gam, a general bureau of gun-powder artillery, was first established. This was suggested by a certain Choi, Mu-Son, who lived in the same city with Lee, Yuan, who was known for supplying saltpetre for the Yuan army. It is from him that Choi, Mu-Son learned the procedure for preparing gun powder. He trained his own workman and proposed the establishment of a general bureau of gun-powder artillery.

2. THE FIRST ROCKET IN KOREA

Choi, Mu-Son had made many kinds of firearms and gun-powder, according to *Koryo Sa* [10] and *Cho Son Wang Cho Silok*. The Running-fire and fire arrow are among the firearms that were made by Choi, Mu-Son between 1377 and 1391. Some types of the Chinese fire-arrows were rocket propelled arrows [11], but Choi's was not – it was only an incendiary arrow for shooting from a bow (Fig. 1).

The structure of Choi's fire-arrow was as follows, according to the "Firearms Illustration" of *Kuk Cho Ore Sorye*, which used Korean measures for description of firearms. The author has converted the Korean measurement system into the metric system: chuck (312.4 mm), chun (31.24 mm), pun (3.124 mm), le (0.31 mm) [12].

2.1 Fire Arrow (Hwa-Jeon)

"The arrow shaft is made of bamboo stick. Its length is 756 mm, circumference 34.36 mm, the arrowhead is made of iron, weight 11 g. Its blades are 14.68 mm wide and 18.74 mm long. Its root is 47 mm long. The tail fins of the arrow are made of feathers, 15.6 mm wide and 194 mm long. The motion chamber, which is 116 mm long and circumference 93.72 mm, is covered with paper or cloth and is covered with oil as a protection against wind and rain. It is attached to the stem of the arrowhead and is shot from a bow" [13].

The first Korean rocket was called *ju-wha*, which literally means 'running-fire,' and was manufactured between 1377 and 1389 near the end of the Koryo Dynasty (918-1392) by Choi, Mu-Son. Detailed descriptions of running-fire are not available, but indirect information indicate that it was a rocket-propelled arrow.

The great King Se Jong said, in November 1447, to an official Pyeong-An, Ham-Gil province:

"Running-fire is very efficient and incomparable because it can be fired easily using a quiver by a mounted soldier. It is detrimental to the enemy. Its loud noise and shape instill fear and incite surrender. Once used at night, its exhaust flame lighten the fields and shake the enemy's spirits.

"When used where the enemy is lying in ambush, its flame and smoke cause the enemy to disclose themselves for fear. Running-fire does not fly straight and it spends more powder and requires more precaution than cannon..." [14].

There are several reasons that point to Running-fire being a rocket propelled arrow:

"Running-fire can be fired easily using a quiver..." A quiver was not a firearm; it was only an arrow carrier, but Running-fire can be fired from a quiver made of bamboo, paper or cloth, because the rocket launcher was a simple tube to guide the direction of a launching rocket. Therefore Running-fire had a rocket engine.

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* *Based upon a paper read to the 34th IAF Congress in Budapest, October 1983.*

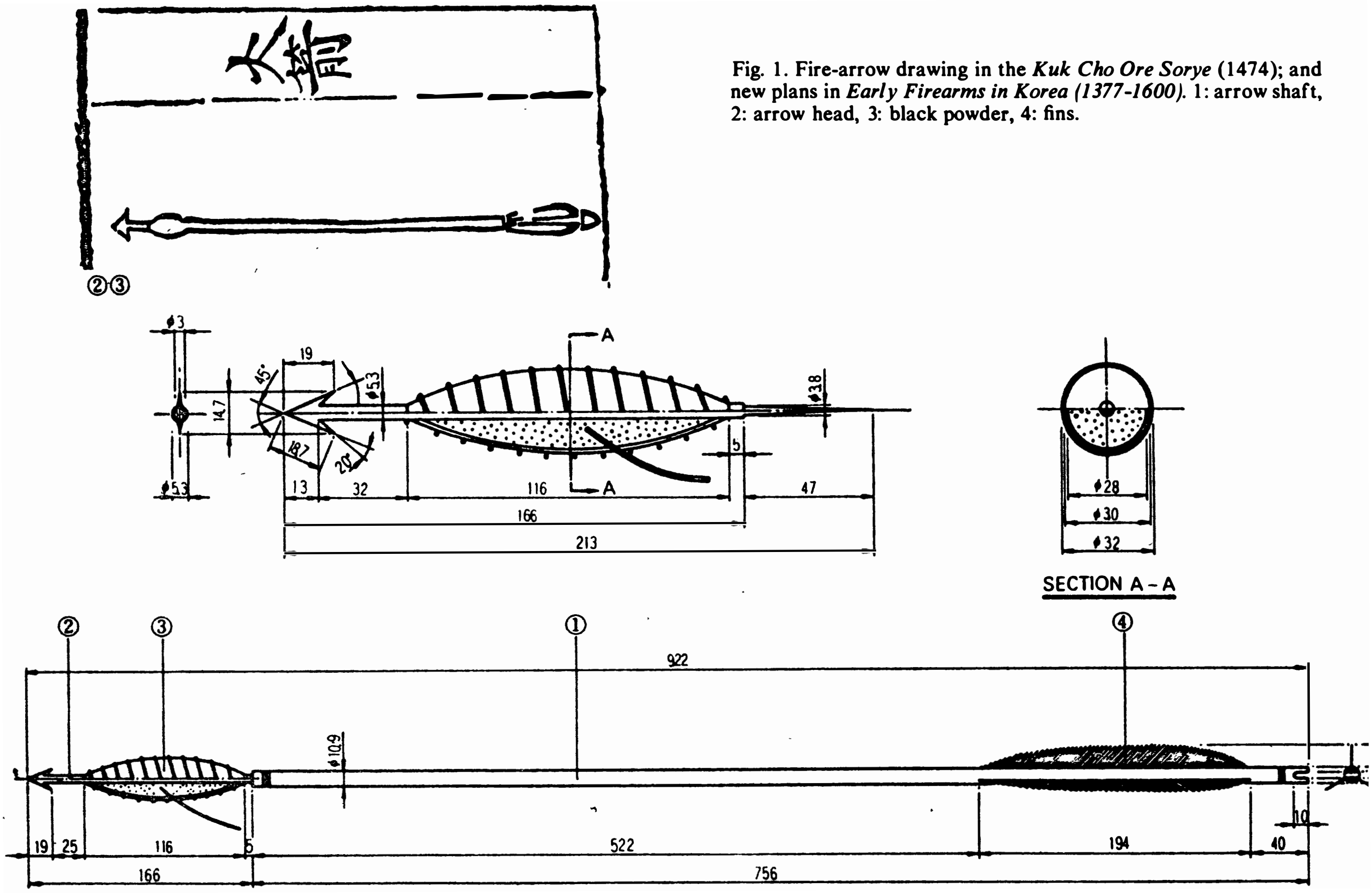


Fig. 1. Fire-arrow drawing in the *Kuk Cho Ore Sorye* (1474); and new plans in *Early Firearms in Korea (1377-1600).* 1: arrow shaft, 2: arrow head, 3: black powder, 4: fins.

"Its loud noise and shape..." A rocket engine is a propulsion device that produces thrust by ejecting combustion gases. Thus, it made loud noises as it ejected combustion gases [15].

"Once used at night, its flame lightens the field... its flame and smoke." If Running-fire were a rifle or a cannon, it could not produce exhaust flames and smoke during flight.

"Running-fire does not fly straight." Motion of the ancient rockets depended on their stabilising sticks which were made from bamboo and with a hole in the powder charge in the propellent case. Thus, rocket-propelled arrows did not generally fly straight.

"Running-fire spends more powder." The weight of a solid-propellant rocket is, for most part, propellant weight. While the rocket propelled arrow is in flight, it continues to eject combustion gas. Thus, Running-fire used more powder than gun or cannon.

According to the *Hwa Po Sick Eon Hae*, a medium Running-fire was charged with 41.4 g of black powder. The weight of the charged black powder of a rocket depended on the volume of the propellant case of a rocket. So, the weight of the propellant of small and large Running-fire was calculated to be 12 g and 2628 g. The large Running-fire, charged with 2628 g of black powder, thus used a significantly larger charge than the largest cannon used in Korea in the 15th century, the *chun- ja- chong- tong*, which was charged with 830 g. A comparison of the weight of the powder charge of rockets and cannon is given in Table 1.

3. THE KOREAN ROCKET OF THE 15TH CENTURY

King Se Jong, who was very much concerned about firearms development, was the fourth king of the Yi Dynasty (1392-1910). Many types of new Korean firearms were developed during his reign (1418-1450). His reign is notable as a turning point in the art of making firearms. The Yi Dynasty had stopped imitating the Chinese models and had created a distinctive Korean style.

By the 29th year (1447) of King Se Jong's reign, Running-fire was developed into three kinds of rocket-propellant arrows: Small-running-fire, Medium-running-fire and Large-running fire.

Korea used many Running-fire, rocket-propelled arrows

TABLE 1. The Powder Charge of Rockets and Cannon.

Rockets		Cannon and Guns	
Name	Weight of Powder	Name	Weight of Powder
Large running fire	2628g	general cannon*	870g
Medium running fire	41.4g	large motor†	870g
Small running fire	12g	victory letter gun‡	26.7g

* The Korean name is the *chun-ja-chong-tong*.
† The Korean name is the *dae-wan-gu*.
‡ The Korean name is the *sung-ja-chong-tong*.

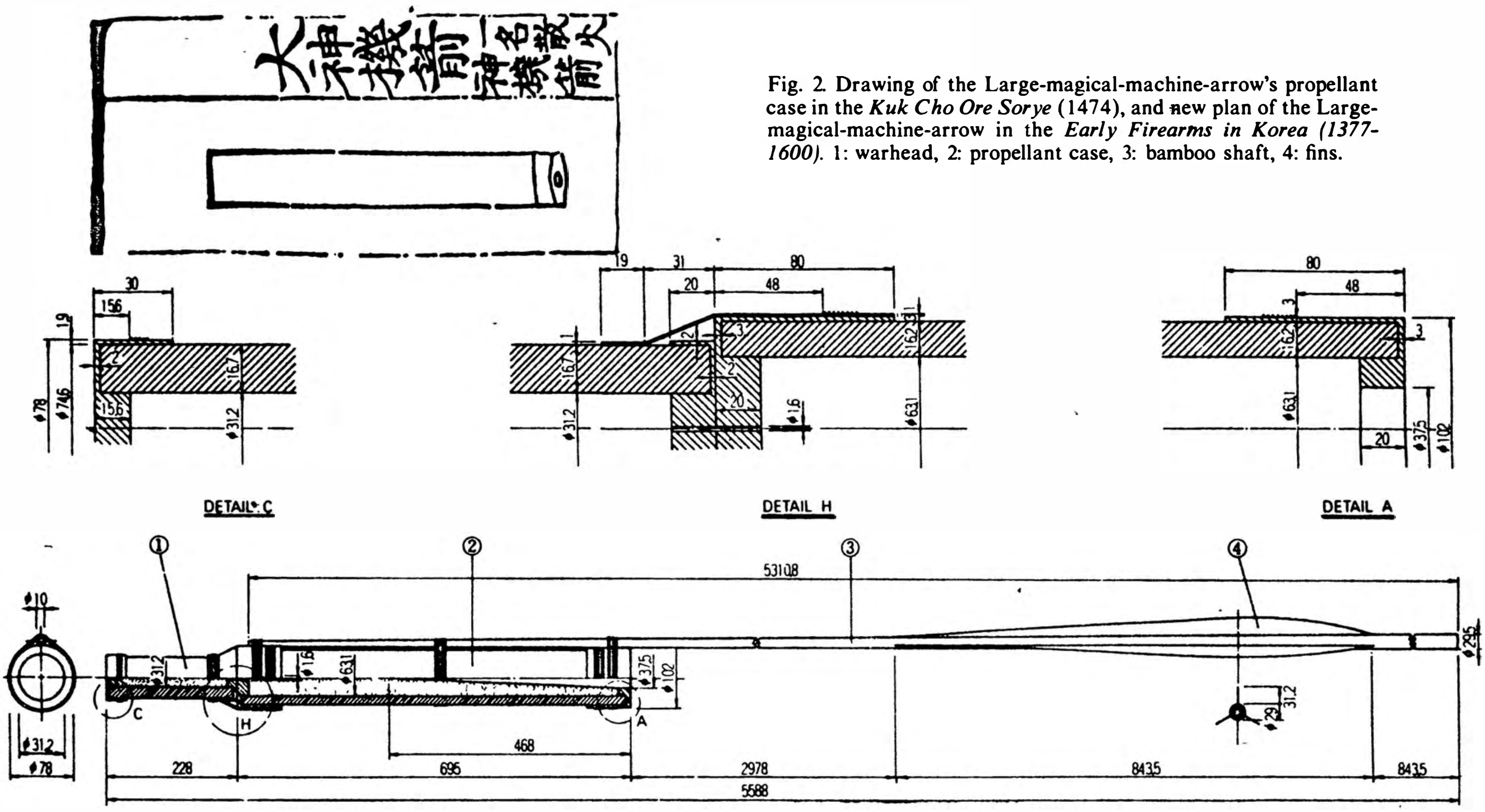


Fig. 2. Drawing of the Large-magical-machine-arrow's propellant case in the *Kuk Cho Ore Sorye* (1474), and new plan of the Large-magical-machine-arrow in the *Early Firearms in Korea (1377-1600)*. 1: warhead, 2: propellant case, 3: bamboo shaft, 4: fins.

until 1448. After 1448, it was not seen in *Cho Son Wang Cho Silok* and, at the same time, new firearms, Magical-machine-arrows, began to be seen in the same book. According to the *Hwa Po Sick Eon Hae*:

The powder tube of the Running-fire is equal to the powder tube of the Medium-magical-machine arrow. The tube of the Medium-magical-machine-arrow is made from one tenth of a paper, which is 2.5 sheets of uncut Korean paper, the length of the powder case is 200 mm, weight of black powder in a powder tube is 44 g" [16].

Dimensions of the Medium-magical-machine-arrow of the *Hwa Po Sick Eon Hae* are the same as in the "Firearms Illustration." The length of the Running-fire powder tube in the *Hwa Po Sick Eon Hae* and the length of the Medium-magical-machine-arrow's propellant case in the "Firearms Illustration" are the same: 200 mm. Therefore, Running-fire was replaced with Magical-machine-arrow (*sin-gi-jeon*).

Four kinds of the Magical-machine-arrow were constructed: small (*so*), medium (*chung*), large (*dae*) and Multiple-bomblets-magical-machine-arrow (*san-haw-sin-gi-jeon*).

3.1 Large-Magical-Machine-Arrow (*Dae-Sin-Gi-Jeon*)

"The propellant case is made of paper, length 695 mm, external circumference 299.9 mm, thickness 17.8 mm, internal diameter 63.1 mm. The length from the end of the propellant case to the attachment twine is 48.42 mm; the diameter of the hole in the bottom is 37.5 mm. The shaft is made of a bamboo stick 5.31 m long, the upper circumference is 31.28 mm; the lower circumference is 93.72 mm. The tail fins are made of feathers, 31.28 mm wide, 843.48 mm long. The length from the end of the bamboo stick to the fins is 843.48 mm " [17].

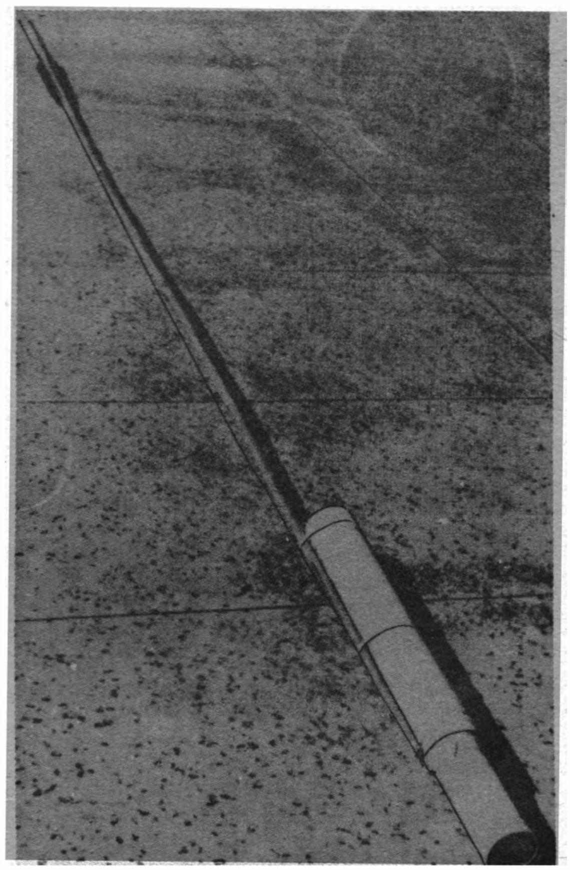


Fig. 3. Large-magical-machine-arrow (Hang-ju Castle Memorial Museum, in Korea).

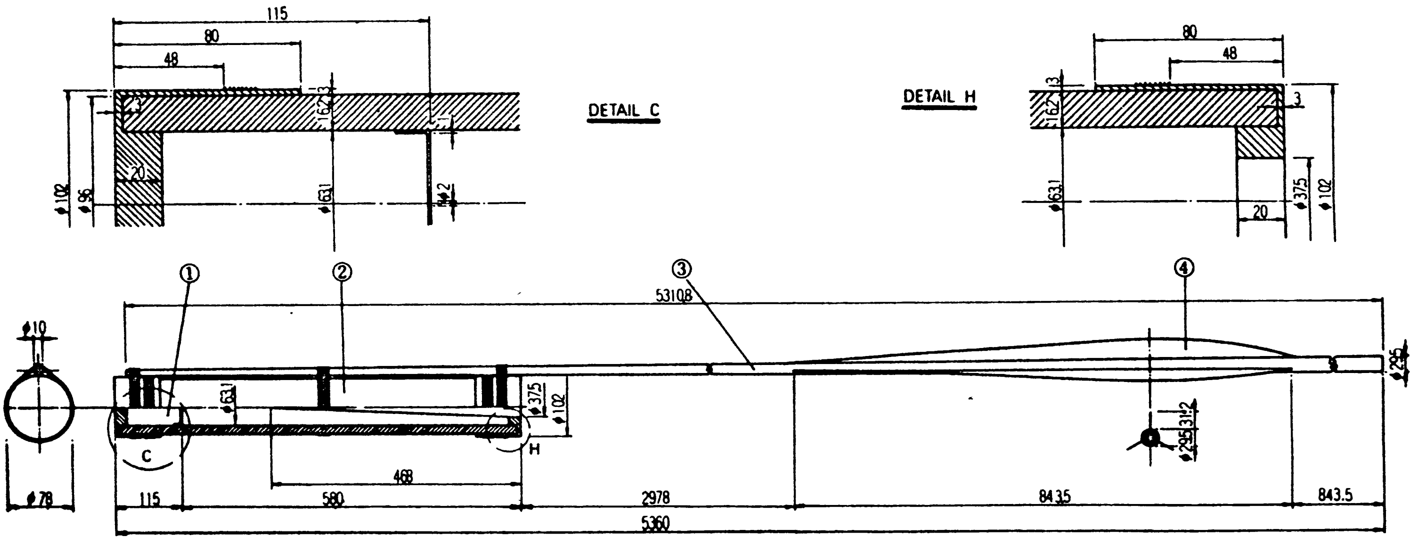


Fig. 4. New plan of the Multiple-bomblets-magical-machine-arrow in *Early Firearms in Korea (1377-1600)*. 1: warhead, 2: propellant case, 3: bamboo shaft, 4: fins.

The detailed internal structure of the Large-magical-machine-arrow's propellant case and warhead was as follows (Figs. 2 and 3). The propellant case was charged with black powder, and the top of it was sealed with paper several times. On top of it, a Large-magical-machine-arrow-explosive-tube (*dae-sin-gi-jeon-bal-hwa-tong*) was attached. The fuse connected the powder of the propellant case to the Large-magical-machine-arrow-explosive tube [18]. The Magical-machine-arrow-explosive-tube used a cylindrical paper tube filled with black powder with both ends capped. The explosive-tube was divided into four compartments: Large-magical-machine-arrow, large, medium and small explosive-tubes.

According to the "Firearms Illustration," the Large-magical-machine-arrow explosive tube was as follows:

"The Large-magical-machine-arrow-explosive-tube is 228.1 mm long, 234.3 mm in circumference, 23.1 mm thick, 31.24 mm in internal diameter and is made of paper. Length from the end of the cylindrical case to the attachment twine is 15.62 mm. It has a hole 3.12 mm in diameter at the bottom into which a fuse is inserted" [19].

3.2 Multiple-Bomblets-Magical-Machine-Arrow (*San-Hwa-Sin-Gi-Jeon*)

The Multiple-bomblets-magical-machine-arrow had almost the same dimensions as the Large-magical-machine-arrow, but the former's warhead system differed from the latter's. Namely, the Large-magical-machine-arrow's warhead was a Large-magical-machine-arrow- explosive-tube attached to the head of the propellant case, but the Multiple-bomblets-magical-machine-arrow's explosive system was in the propellant case.

The detailed internal structure of the Multiple-bomblets-magical-machine-arrow's propellant case and explosive system is as follows (Fig. 4). The lower part of the propellant case was bound with twine as was the Large-magical-machine-arrow. The propellant case was charged with powder up to 579.5 mm, leaving 115.59 mm empty. Several layers of paper were attached to the top surface of the powder. Several Land-fire-tubes (*ji-hwa-tong*) attached to Small-explosive-tubes (*so-bal-hwa-tong*) were placed on top of the propellant case with their fuses attached to the propellant charge [20].

3.3 Medium-Magical-Machine-Arrow (*Chung-Sin-Gi-Jeon*)

"The arrow shaft is made of a bamboo stick. Its length is 1455 mm, upper circumference is 14.68 mm and lower circumference is 24.99 mm. The arrow head is made of iron, weight 5.5 g. The stem of the arrowhead is 37.4 mm long and 16.56 mm in circumference. Its blades are 13.4 mm wide and 181.2 mm long. The propellant case, 200 mm long, is made of paper, its external circumference is 8.75 mm and its thickness is 6.2 mm, internal diameter is 16.6 mm. The length from the end of the propellant case to the attachment twine is 9.37 mm, the diameter of hole in the bottom is 7.19 mm" [21]

The detailed internal structure of Medium-magical-machine-arrow propellant case is as follows (Figs. 5 and 6):

The lower part of the propellant case was bound with twine as in the Large-magical-machine-arrow's propellant case. The propellant case was charged with powder up to 175.01 mm, leaving 24.99 mm. A small explosive tube (*so-bal-hwa-tong*), 56.23 mm long, 47.8 mm in circumference, 4.37 mm thick and 6.87 mm in internal diameter was inserted. The length from the end of the cylindrical case to the attachment twine was 6.25 mm, and the diameter of the nozzle was 2.19 mm. Finally, the powder of small explosive tube and the powder of the Medium-magical-machine-arrow's propellant case were connected with fuses [22].

3.4 Small-Magical-Machine-Arrow (*So-Sin-Gi-Jeon*)

"The arrow shaft is made of bamboo stick 1030.9 mm long. Its upper circumference is 14.68 mm and the lower circumference is 24.99 mm. The arrow head of the Small-magical-machine-arrow is the same as that of the Medium-magical-machine-arrow. The three tail fins of the arrow are made of feathers, 14.68 mm wide and 146.83 mm long. The 153.08 mm long propellant case is made of paper. Its external circumference is 67.17 mm, 5.0 mm thick, internal diameter 11.56 mm, length from the end of the propellant case to the attachment twine (bound the same way as Large-magical-machine-arrow's propellant case) is 9.37 mm. It is charged with powder in the same way as the Land-fire tube; the diameter of the nozzle in the bottom is 4.06 mm. It does not have any explosive tube" [23] (Fig. 7).

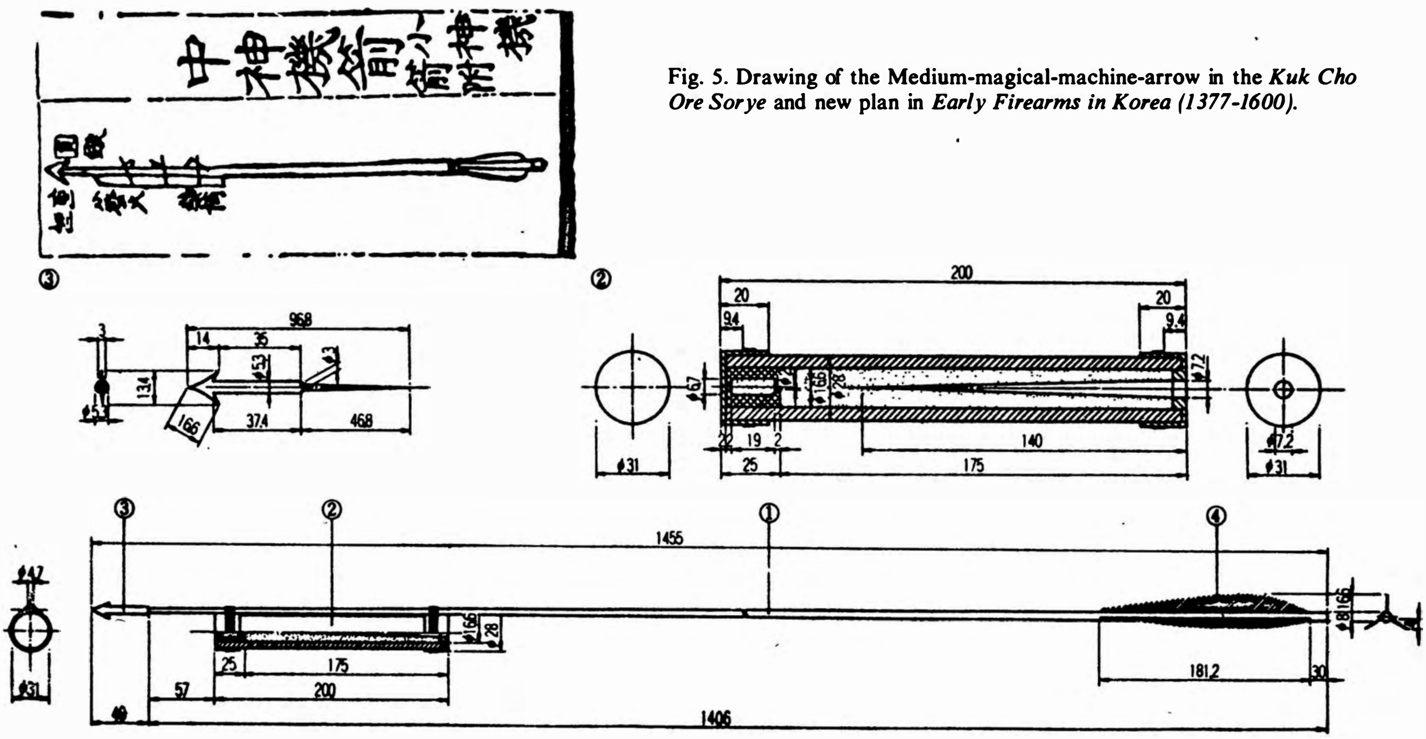


Fig. 5. Drawing of the Medium-magical-machine-arrow in the *Kuk Cho Ore Sorye* and new plan in *Early Firearms in Korea (1377-1600)*.

4. THE MANUFACTURING METHOD OF THE ROCKET'S PROPELLANT CHARGE

"A long, cone-shaped awl was inserted through the hole in the bottom of the propellant case, then a small quantity of powder was spread and hardened with empty cylindrical iron stick. This process was repeated until the case was filled up to the desired level. The long awl was removed, leaving the cone-shaped central cavity in the charged propellant case [24] then a fuse was inserted.

"The external diameter of the cylindrical iron stick was equal to the internal diameter of the propellant case. The internal diameter of the cylindrical iron stick was equal to the diameter of hole in the propellant case's bottom" [25].

According to the ***Wu Pei Chih***, "If the rocket-propelled arrow is to fly straight, the hole must be straight otherwise it will go off at a tangent" [26]. It was thus very important to make the rocket engine correctly.

Korean rockets had a paper tube rocket that was attached to the top of the bamboo stick for stabilisation to help the Magical-machine-arrow fly straight. Notably, the large Korean rockets had three fins attached to the bamboo stick [27].

The paper propellant case [28] had a hole in the bottom believed to be the place for the nozzle where the flame of the propellant gases were ejected. The Korean rocket's ratio of nozzle diameter to the internal diameter of propellant case was 1:2.3. Large, Multiple-bomblets and Medium-magical-machine-arrows had a warhead or explosive on top of the propellant case designed to explode over the target area.

Korea had 33,000 Running-fires and Magical-machine-arrows in 1447 [29], which was a large number for rocket weapons.

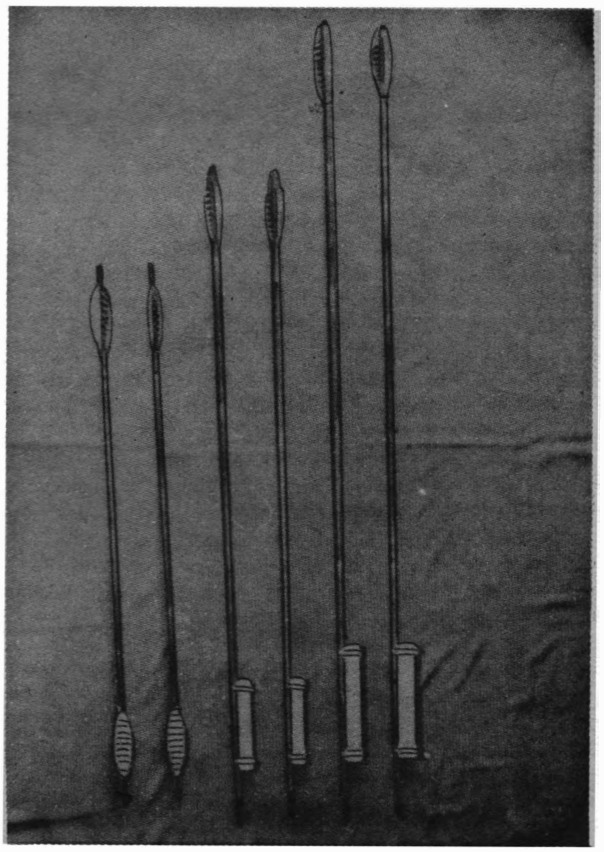


Fig. 6. Fire-arrows, Small and Medium-magical-machine-arrows (Hang-ju Castle Memorial Museum, in Korea).

5. ROCKET LAUNCH DEVICE

King Mun Jong was very interested in the development of firearms; when he was the Crown Prince, he was one of the persons responsible for the Bureau of Weapons. He invented the fire-cart (*hwa-cha*), shown in Fig. 8, used to launch large numbers of rockets rapidly and also to transport them.

According to the ***Mun Jong Sillok*** (Veritable records of

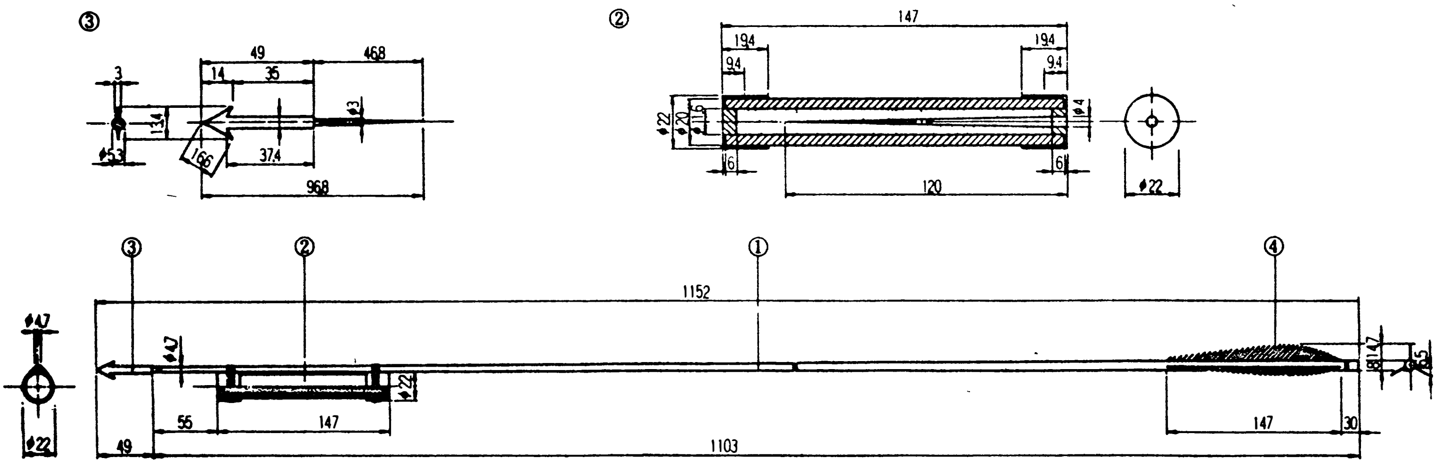


Fig. 7. New plan of the Small-magical-machine-arrow in *Early Firearms in Korea (1377-1600).*

the King Mun Jong era), the fire-cart was invented and tested in February 1451, by King Mun Jong, the 4th King of Yi Dynasty [30].

There was a wooden launcher on top of this vehicle, on which were installed 100 Medium-magical-machine-arrows or 50 Four-arrow-guns.

The detail structure of the fire-cart according to the "Firearms Illustration" follows below.

5.1 Fire-Cart

"The diameter of the wheel is 874.7 mm. The hub is made of wood, 224.9 mm wide and 206.2 mm in diameter. Each wheel has 15 spokes. The axletree is made of wood, 1312.1 mm long, and consists of three parts: a middle square pillar 687.3 mm long and two 312.4 mm long end columns which are inserted into two wheels. Two wide posts, 546.7 mm long, 234.3 mm wide, and 62.5 mm thick are set up at both ends of the top side of the middle square pillar. A small post, that has a square bottom pillar of length 231.2 mm and a round upper pillar of length 453.0 mm, is set up at the centre of the square pillar. Thin wooden boards are attached between each wide post and the small two-part post. A lower centre crossbar, 546.7 mm long, 118.7 mm wide, and 46.9 mm thick, which has a hole in the centre for the small post, is placed on the two wide posts. Two yokes, 2311.8 mm long, are set up at both ends of the wide posts. It consists of two parts: a four-cornered part, 874.7 mm long, 94.7 mm wide, 103.1 mm thick and a column, 1437.0 mm long and 46.7 mm in diameter. An upper centre crossbar, whose length, width and thickness are the same as that of the lower centre crossbar, is placed between the end of both wide posts. It has a hole in the centre for the small post. A rear crossbar whose length and width are the same size as centre crossbars but is 78.1 mm thick. It is attached at the rear (four-conered part) of both yokes. Several thin wooden boards are attached between the rear crossbar and the upper centre crossbar. This forms a wooden box to hide some arms. Its length and width are 624.8 mm by 515.5 mm.

"Four U-shaped nails are driven into the front and middle of the column part of the yokes to insert rods, which are used to pull the fire-cart."

The cart could be drawn by two men on level ground, but it would require another man pushing from behind when going uphill, and two more men had to push the cart when it was going up a steep hill [31].

New plans for the fire-cart (Fig. 9) are made from the above explanations and an original drawing for the fire-cart in "Firearms Illustration."

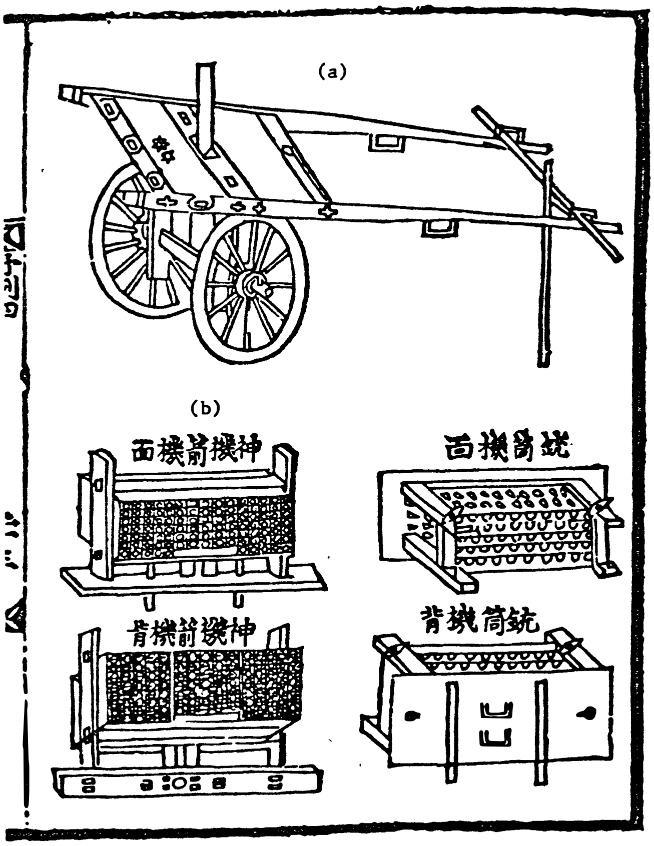


Fig. 8. Drawing of the fire-cart (A) and Magical-machine-arrow-launcher (B) in the *Kuk Cho Ore Sorye.*

It carried a Multiple-rockets-launcher (*sin-gi-jeon-gi*) or a box installed with 50 Four-arrow guns [32] which can shoot 200 Thin-arrows [33] at the same time.

5.2 Magical-Machine-Arrow-Launcher (*Sin-Gi-Jeon-Gi*)

"The first crossboard is 1171.55 mm long, 109.3 mm wide, 46.9 mm thick and has a 62.4 mm diameter hole in the centre into which the small post of the fire-cart is inserted. Two small square columns which are 171.8 mm long, 62.4

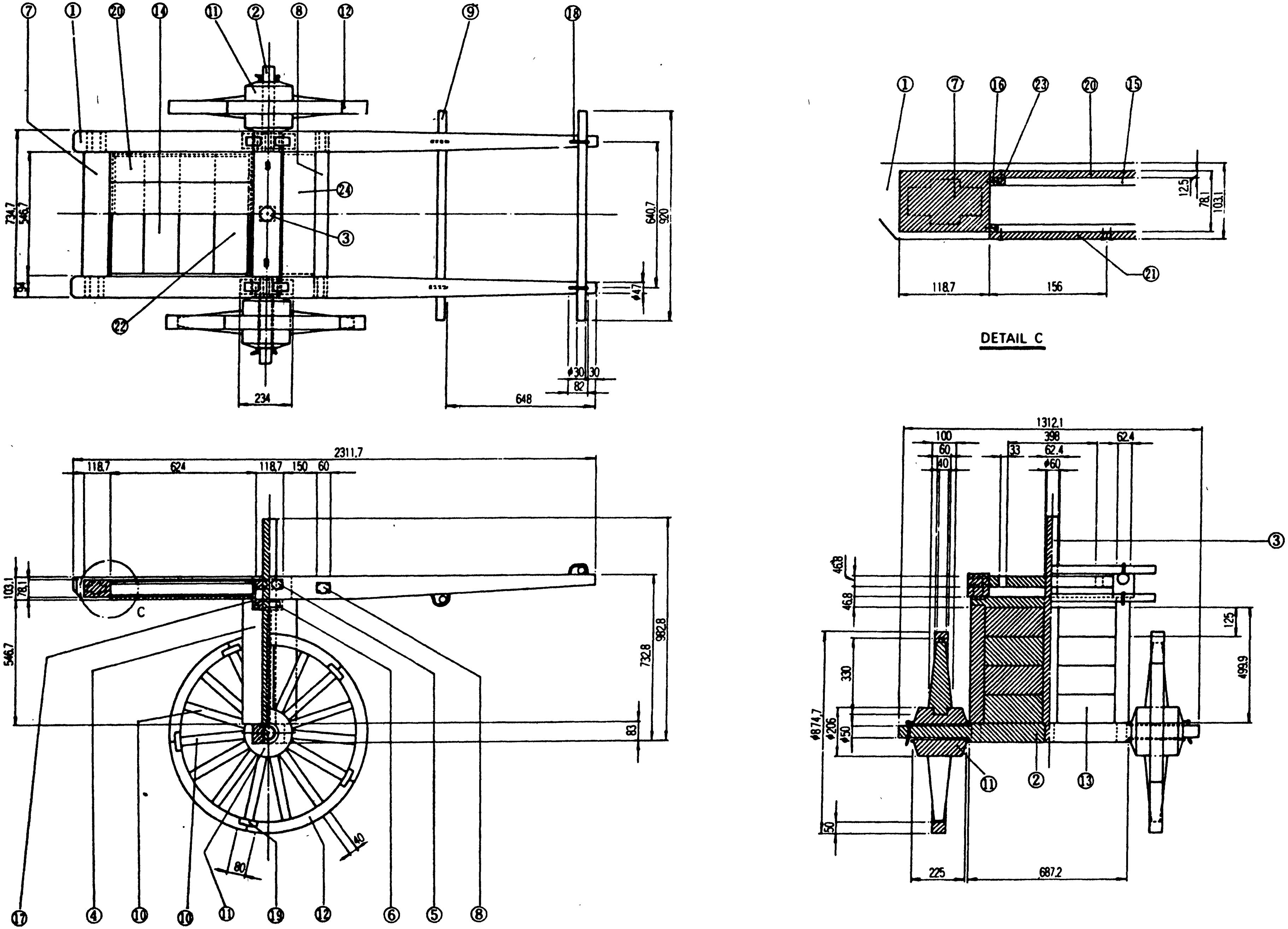


Fig. 9. New plan of the fire-cart in *Early Firearms in Korea (1377-1600)*. 1: yoke, 2: axletree, 3: small post, 4: wide post, 5: upper centre crossbar, 6: lower centre crossbar, 7: rear crossbar, 8: front crossbar, 9: rod, 10, 19, 13, 17, 20, 22, 24:thin wooden board, 15, 16, 21, 23: thin wooden beam, 18: U-shape nail.

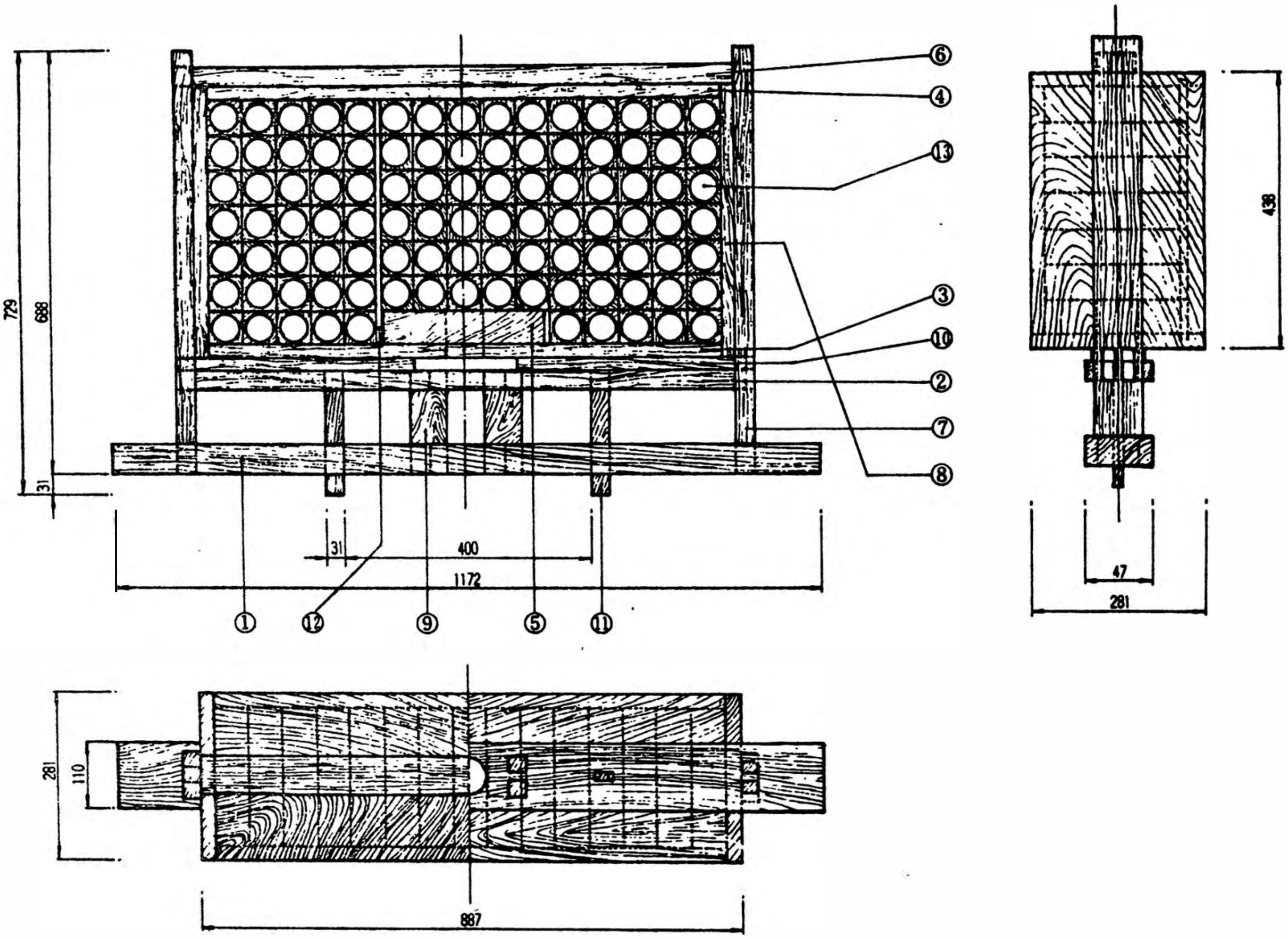


Fig. 10. New plan of the Magical-machine-arrow-launcher in *Early Firearms in Korea (1377-1600)*. 1: the first crossboard, 2: the second crossboard, 3 & 4: top and bottom wide boards, 5: rectangle block of wood, 6: the third crossboard, 7: column, 8: side wide board, 9: small square column, 10: detailed board, 11: assistant column, 12: thin column, 13: cylindrical-hole-wood-block.

mm wide and thick, are set up on either side of the hole in the crossboard. Two columns, 687.3 mm height, 78.1 mm wide and 31.2 mm thick, are set up near the end of the first crossboard. The spacing of the columns is 843.5 mm. The second crossboard, 843.5 mm long, 109.3 mm wide and 31.2 mm thick, has a hole in the same position as the first crossboard. It is positioned 87.5 mm above the first crossboard. Two detailed boards, 359.3 mm long and 87.5 mm wide, are set up on top of the second crossboard such that the outside ends of both detail boards are attached to both columns. Two assistant columns, 203.1 mm long, 31.2 mm wide and 15.6 mm thick, are set below the two detail boards, the spacing of the assistant columns is about 187.4 mm. Both ends of the assistant columns project 31.2 mm below the first crossboard. Four wide boards are attached between the two columns and the second crossboard. This results in a shallow rectangle box. The top and bottom wide boards have a length of 827.8 mm, a width of 281.2 mm and a thickness of 21.9 mm. The right and left wide boards have a length of 437.4 mm; the width and thickness are the same size as top and bottom. At the centre of the bottom wide board is a hole, which is the same size as that of the second crossboard. A rectangle block of wood, 265.5 mm in length, 234.3 mm in width, and 56.2 mm in thickness, has the same size hole in it as does the second crossboard. The block is 234.3 mm long, 56 and 2 mm wide and thick and has a cylindrical hole, 234.3 mm long, 46.9 mm in diameter bored through it to be loaded a Medium-magical-machine or a Small-magical-machine-arrow (rocket).

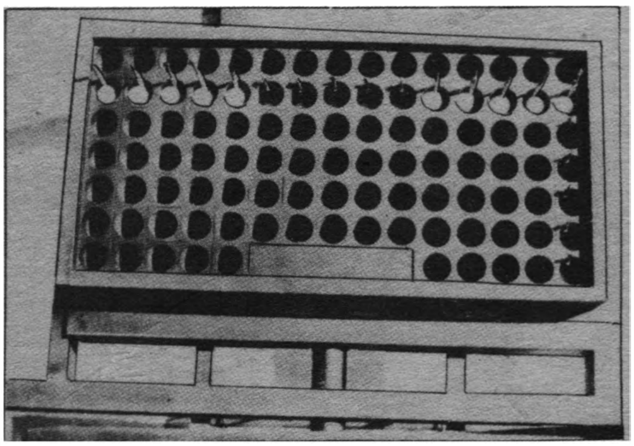


Fig. 11. Magical-machine-arrow-launcher with medium and Small-magical-machine-arrows.

"There are 100 cylindrical holes in the blocks in the shallow rectangle box. It consists of seven rows of blocks. The first row has five blocks on both sides of the rectangle block of wood, and all of the other rows have 15 blocks. The end of the block is pierced with a wire, and both ends of the wire are attached to the right and left wide boards.

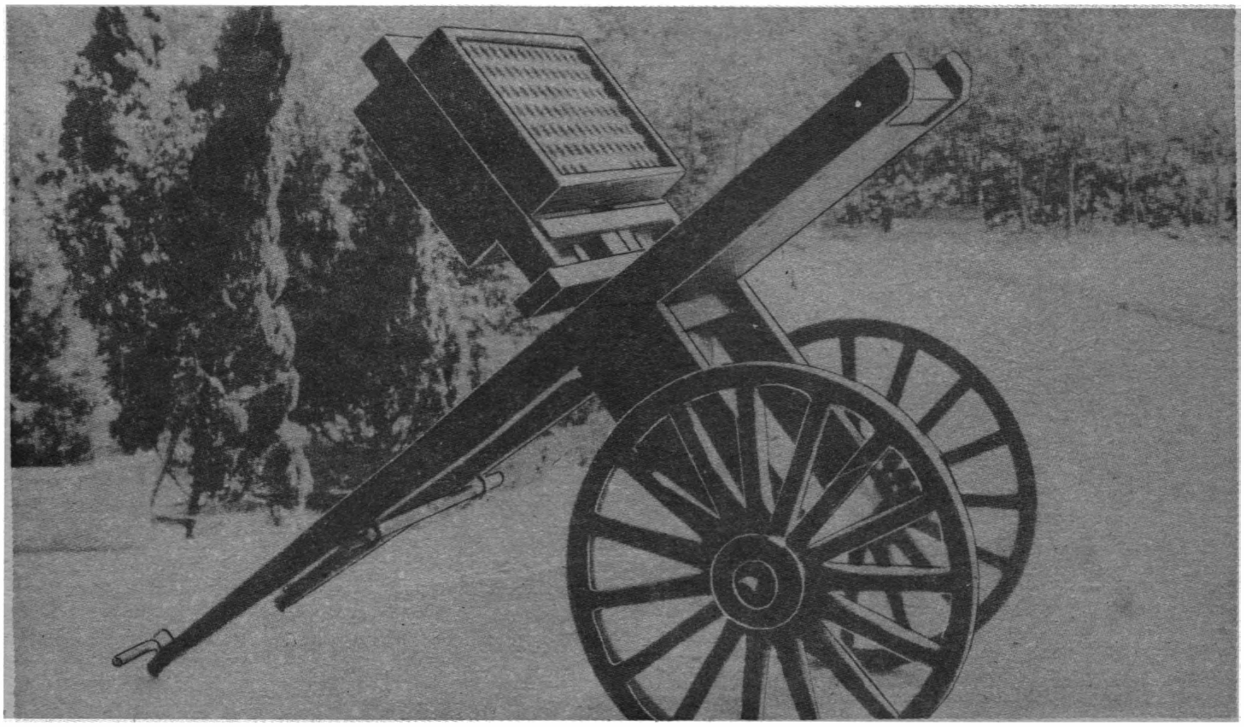
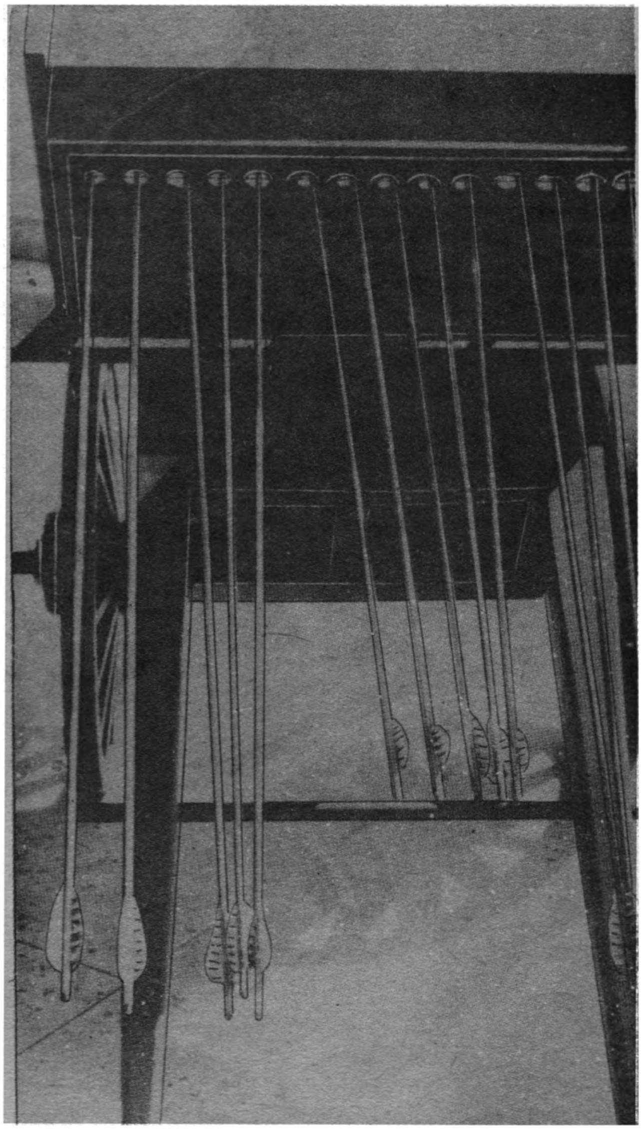


Fig. 12. Fire-cart and Magical-machine-arrow-launcher (Hang-ju Castle Memorial Museum in Korea).



"Finally, the third crossboard, which measures 843.4 mm in length, 62.4 mm in width, and 31.2 mm in thickness, is set up on the top wide boards [34].

The author has produced a plan (Fig. 10) of the Magical-machine-arrow-launcher from the above explanations and a drawing (Fig. 8) of the Magical-machine-arrow-launcher. He has constructed a Magical-machine-arrow-launcher (Fig. 11) and fire-cart (Fig. 12) from these plans.

The fire-cart and the Magical-machine-arrow-launcher were scientifically designed. A cart body that was raised above the axle by short pillars regulated the angle from zero to 43 degrees, so that the rocket launch angle could be varied through that range. The Magical-machine-arrow-launcher had 100 rocket launching holes. Therefore, it could launch 100 Medium or Small-magical-machine-arrows in groups of 15 at a time, in quick succession. In peace time, the fire-cart, without its launcher, was used as a simple cart. It was a useful multiple-rocket launcher cart.

According to the *Mun-Jong-Sillok*, 700 fire-carts were built in Korea in 1451 [35].

Documents on the Large-magical-machine-arrow's launcher have not been found, but the length of the Large-magical-machine-arrow's was 5.7 m; therefore, it used a large special launcher.

These weapons are believed to have been used as weapons to fight against Chinese and Japanese bandits.

6. CONCLUSIONS

The first Korean rocket the Korean name of which is *ju-hwa* (Running-fire), was used between 1377 and 1447. In 1448, it was replaced with the Magical-machine-arrow (*sin-gi-jeon*) which was built in four configurations, small, medium, large and Multiple-bomblets-magical-machine arrow. The Large-magical-machine-rocket-propelled arrow's cylindrical paper case was 70 cm long and 9.5 cm

in exterior diameter. It was attached to a 5.3 m bamboo guide stick. The warhead was attached to the head of the propellant case. It was a large paper propellant case rocket.

The detailed structure of the four kinds of Magical-machine arrow in Korea after 1448 furnish information on the early oriental rocket's detailed structure.

The drawing of the Medium-magical-machine-arrow (Fig. 5) in the *Kuk cho ore sorye* seems to be the oldest drawing of any oriental rocket arrow.

The fire-cart, Multiple-rockets-launcher-cart, was scientifically designed to launch 100 Medium or Small-magical-machine-arrows in groups of 15 at a time, in quick succession. The angle of the launch was controllable from zero to 43 degrees.

Even in the 15th century, Korean rockets were manufactured with considerable precision, as evidenced by the use of a unit of measurement known as the "le" (0.31 mm).

NOTES AND REFERENCES

1. New plans were introduced in the book, *Early Firearms in Korea (1377-1600)*, Il-ji Publishing Co., Seoul (1981) by Chae, Yeon Seok. They were made from the descriptions and drawings in the *Kuk Cho Ore Sorye*. These plans were used to build copies of all the firearms used from 1448 to 1451 (four types of rockets, 13 versions of guns or cannon, six models of bombs, 13 different projectiles, a rocket launcher cart, and an armed cart). Some of these were fired in January 1981. All of these firearms are on permanent display at the Hang-ju Castle Memorial Museum, near the city of Seoul in Korea.
2. *Kuk Cho Ore Sorye*, "Firearms Illustration" Vol. 4 (1474), officially compiled in 1474.
3. Ho, Son-Do, *Rok Sa Hak Po*, **24**, 1.60 (1964); **25**, 39-98 (1965), and **26**, 141-165 (1965).
4. "The development of Firearms in Korea 1474-1592," *Rok Sa Hak Po*, **30**, 40-107 (1966); **31**, 67-127 (1967). "On the Chon-ja cannon dated 1555," *Mi Sul Cho Ryo* (National Museum of Korean Art Magazine), **10**, 5-14, (1965).
5. Veritable record of the Yi Dynasty, 1413-1865, which was compiled by the veritable record office, Yi Dynasty.
6. "Modern Firearms," in Jeon, SangWoon, *Science and Technology in Korea: Traditional Instruments and Techniques*, pp. 184-206, MIT Press, Massachusetts, (1974). The author seems to have misunderstood the difference between "arrow" and "rocket." The Korean name *Jeon*, literally means 'the arrow;' but the author translated it for the English word 'rocket.' Generally, an arrow is not a rocket, but some special arrows were rockets.
7. Boots, T. L., "Korean Weapons and Armor," *Transactions of the Korea Branch of the Royal Asiatic Society*, **XXIII**, Part II, (1934).
8. Winter, F. H., "The Genesis of the Rocket in China and its Spread to the East and West," XXXth Congress IAF, Paper IAF-79-A-46, p. 13 (1979). The author mentioned Korean rockets as follows, "Elsewhere in Asia, Montross says the Koreans... But Hagerman, in his detailed study of these engagements, mentions no rocket, only cannon, Partington does not mention Korean rocket weapons..."
9. Wang Ling, "On the Invention and Use of Gun-Powder and Firearms in China," *Isis*, **37**, 176 (1947).
10. *History of Koryo Dynasty*, officially compiled by Chong, In-Ji, *et al*, in 1451. Modern reprints, Yonsei University Press, Korea (1955).
11. Chae, Yeon-Seok, "A Study of the Korean Fire-Arrows," *J. of Korean Science History*, **2**, (1979). "Korean Fire-Arrow," *Early Firearms in Korea (1377-1600)*, pp. 22-38 (1981). Sun, Fang-Toh, "Rockets and Rocket Propulsion Devices in Ancient China," XXXI Congress IAF, Paper IAF-80-IAA-02, p. 9 (1982).
12. Park, Heung-Su, "A Study of the Korean Measures," *Dae Dong Mun Hwa*, **4**, (1967).
13. *Kuk Cho Ore Sorye*, **4**, p. 21.
14. Ho, Son-Do, *op. cit.* (part 3), *Rok Sa Hak Po*, **25**, p. 71.
15. Sutton, G. P. and Ross, D. M., *Rocket Propulsion Elements: An Introduction to Rocket Engines*, 4th ed., p. 1, Wiley & Sons, New York (1976).
16. Lee So, *Hwa Po Sick Eon Hae*, p. 32, (1635).
17. *Kuk Cho Ore Sorye*, **4**, 20-21.
18. There is an "explosive tube" in the description of the Large-magical-machine-arrow, but the Large-magical-machine-arrow-explosive-tube is among the kinds of explosive-tubes in the "Firearms Illustration." Therefore, the explosive-tube of the Large-magical-machine-arrow meant a Large-magical-machine-arrow-explosive-tube.
19. *Kuk Cho Ore Sorye*, **4**, 17-18.
20. *Ibid.*, pp. 20-21.
21. *Loc. cit.*
22. *Loc. cit.*
23. *Loc. cit.*
24. Davis, T. L. and Ware, J. R., "Early Chinese Military Pyrotechnics," *J. of Chemical Education*, **24**, 532 (1947); the author called it "the central cavity in the rocket propelling charge" in his study.
25. *Kuk Cho Ore Sorye*, **4**, 17.
26. Davis, T. L., *op cit.*, p. 532.
27. Other large rocket-propelled-arrows did not use fins on a stabilising stick. A. Ingemar Skoog, "The Swedish Rocket Corps 1833-1845," *Essay on the History of Rocketry and Astronautics*, NASA CP-2014, **1**, 10-20, Fig. 2, 12. F. W. Foster Gleason, "Lost Causes," *Gun Digest*, ed. John T. Amber, pp. 36-39. Winter F. H., "On the Origin of Rockets," *Chemistry*, **49**, No. 2, 10 (1976).
28. "Rocket, an artificial fire-work, consisting of a cylindrical case of paper..." *Encyclopaedia Britannica*, London: Andrew Bell and C. Macfaraunar, Vol. 3, p. 553 (1771). According to this, rocket propellant cases were made with paper until 1771.
29. Ho, Son-Do, "The Introduction and Development of Firearms in Korea 1356-1474," part 2, p. 52.
30. *Kuk Cho Ore Sorye*, pp. 22-24.
31. Jeon, San-Won, *Science and Technology in Korea*, p. 199.
32. It was one of the Korean guns in 1448. It was able to give four thin-arrows (bullets) at the same time. Its barrel length was 180.1 mm and the diameter of muzzle was 21.9 mm. Therefore, it was called a Four-arrow-gun.
33. It was one of the bullets in Korea in 1448. It was like a small arrow, total length was 218.6 mm.
34. *Kuk Cho Ore Sorye*, **4**, 25-26.
35. Chae, Yeon-Seok, *Early Firearms in Korea (1377-1600)*, p. 169.

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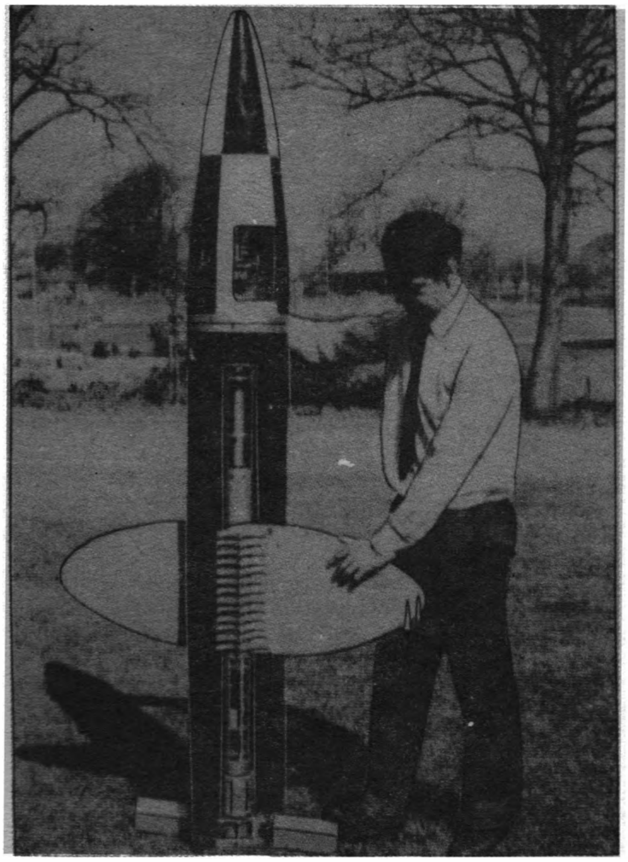
REPORT ON THE 18TH IAA INTERNATIONAL SYMPOSIUM ON THE HISTORY OF ASTRONAUTICS LAUSANNE, SWITZERLAND, OCTOBER 1984

Eleven papers were presented at this symposium, held in two sessions on 9 and 11 October 1984 under the joint chairmanship of Fred Durant (USA) and Professor Sokolsky (USSR). The first session began with a paper by Eric Burgess that told the story of the many astronomy, rocket and space flight societies that sprang up in Britain just before the Second World War. The presentation was illustrated by a remarkable series of slides from Burgess's own archive, showing events and personalities linked with the rocketry movement in Britain between 1935 and 1945. Most of these groups were short-lived, but the more active ones eventually combined with The British Interplanetary Society when it resumed operations at the end of the war. Eric Burgess, who now lives in California, was a founder member of one of these groups, the Manchester Interplanetary Society. This Society received some unfortunate publicity when it began experimenting with home-made solid fuel rockets. This was judged to be contrary to the Explosives Act of 1875 but, fortunately, charges were dropped.

Two other British papers were presented in this session. This is worthy of note in itself as participation from this country in previous History of Astronautics meetings has been low. The first, by John Becklake, from the Science Museum in London, described the rocket work carried out in Britain during the Second World War. The development of the 5 cm and 7.5 cm solid fuel anti-aircraft and barrage rockets that saw action in many campaigns has been relatively well documented. What is not so well known is that several rocket-propelled guided missile projects were started during the war. None reached the operational stage, but the most developed by the end of the war, Brakemine, had made many sucessful test flights. This was a joint Anti-Aircraft Command/A. C. Cossor Ltd. project. The paper outlined the progress on this project and those of the LOPGAP, Stooge and Longshot (Little Ben) missiles. The other paper, by John Griffiths, also from the Science Museum, presented for the first time details of the liquid fuel rocket research carried out by Isaac Lubbock and Geoffrey Collin of the Asiatic Petroleum Company (now Shell) during 1941 and 1943. Lubbock's team was given a contract from the Ministry of Supply to study liquid fuel rocket motors for possible use as RATO units. The engine they developed, affectionately known as Lizzy, produced a thrust of 910 kg using a liquid oxygen/petrol mixture. However, this work was not pursued and it is interesting to note that of the four missile systems being developed in Britain at the end of the war only one, LOPGAP, employed a liquid fuel motor.

Two USSR papers and one by F. Zaganesku from Rumania completed the first session. Zaganesku described the work of three Rumanian rocket pioneers and a paper by V. P. Mikhaylov from the USSR Academy of Sciences listed the contributions of Russian scientists and engineers through the ages to the development of rocketry and space flight. Much emphasis was placed on the ideas of Tsiolkovsky. K. V. Phrolov and A. A. Parkomento, also from the USSR Academy of Sciences, reviewed the work of A. A. Blagonravov, the famous Russian scientist. Blagonravov, who died in 1975, began his space science career in upper atmosphere research but was also well known and respected in the field of the history of astronautics.

Subjects covered during the second session ranged from a paper by Fang-Toh Sun from Taiwan entitled "On the Early Rocket Weapon of China" to "A History of Heat Shields for US Manned Spacecraft" by L. Ronquillos of Martin Marietta Aerospace. Fang-Toh Sun, taking evidence



Brakemine missile. This is on display at the REME Museum, Arborfield.

Science Museum

from early original Chinese sources, argued that the "fei huo tsiang" (literally flying fire lance) weapons used in the Battle of Khaifeng-fu in 1232 were true, although primitive, rocket weapons. He also reviewed the progress made in Chinese rocket weapons up to the 17th Century.

One of the most interesting papers in this session was presented by Fred Ordway of the Alabama Space and Rocket Center. In 1877 the Italian astronomer Schiaparelli reported that he had detected a network of fine lines on Mars using a 22 cm telescope at Milan University. He called them "canali" which to Schiaparelli meant channels or grooves; he certainly did not ascribe an artificial origin to them. However, his report gave credence to the idea that intelligent beings inhabited Mars and one of the greatest supporters of this theory was the American Percival Lowell. Lowell made it his life's work to prove these theories. Ordway's paper discusses the influence of this controversy on the Science Fiction literature of the time.

The session ended with an excellent review paper co-authored by Fred Ordway and H. Moulin of ECOMEX, Paris entitled "Rocketing in Nineteenth Century France." Although French interest in rocket weapons during this period was not as great as in Britain or Russia, a small group of enthusiasts carried out work mainly between 1810 and 1860.

Dr. E. J. Becklake

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A HISTORY OF INERTIAL GUIDANCE

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This article deals with the development of inertial guidance systems for ballistic missiles. It covers the evolution of guidance devices from the early days of experimentation during the 1930's, through the operational use of the work-horse LEV-3 system on the German V-2 rockets, to the reliable and accurate guidance mechanisms of today. Personnel of the Army Ballistic Missile Agency Laboratories, with experience dating as far back as pre-World War II days, made great contributions to the advancement of the art, science and engineering of inertial guidance systems.

Although inertial guidance systems have been greatly improved in the past few years, much work remains to be done if adequate guidance is to be provided for the exploration of outer space. Present systems can provide guidance only for a relatively short distance. Vehicles travelling to or landing on planets and returning to the Earth will require even more precise guidance systems and/or supervision by celestial tracking. New concepts in guidance instrumentation may have to be developed.

1. HISTORICAL BACKGROUND

Inertial guidance is a self-contained system which can guide and control missiles without signals from the ground. The guidance to the target includes sensing and correction of disturbing forces such as winds and uneven thrust from power plants. The gyroscopic principles on which inertial guidance is based are taken from Newton's laws of motion.

Inertial guidance has been adapted for use in ballistic missiles so that they can now be sent to targets thousands of miles away. This type of guidance is particularly useful for long-range missiles operating over hostile territory. Because the inertial guidance system does not rely on electronic signals from the ground, it cannot be jammed by electronic countermeasures.

Measurement of accelerations is the basis for most inertial guidance systems. In the most recently developed systems, a gyro-stablised platform serves as a basic reference for measuring the magnitude and direction of the accelerations. This platform is stabilised by three gyroscopes, one for each of the three missile axes (Fig. 1). Gyro-type accelerometers, mounted on the stablised platform, measure accelerations in predetermined directions.

Inertial guidance systems for missiles were not developed overnight. In 1934 the Germans first attempted to control a missile by inertial means. This first system was rather crude, but it paved the way for present day inertial guidance systems. During the past 25 years, instruments and controls have been developed and refined towards its achievement of pin-point accuracy in guiding missiles over long distances. The successes to date are but the beginning. Still greater refinements are necessary to guide missiles accurately over longer distances and into outer space.

* Editors note. Since this paper was first published in 1959, the reader must keep the year in mind. Indeed, it is a quarter of a century old. Its historical significance lies in the fact that it presents the history of inertial guidance up to that time. It was published in a very limited number of copies, few of which survive, by the US Army Ballistic Missile Agency, a forerunner of the present US Army Missile Command. Dr. Mueller was, at the time, deputy director of the agency's Guidance and Control Laboratory. Formerly, in World War II, he had helped to develop the guidance and control unit for the V-2 missile and other German rockets.

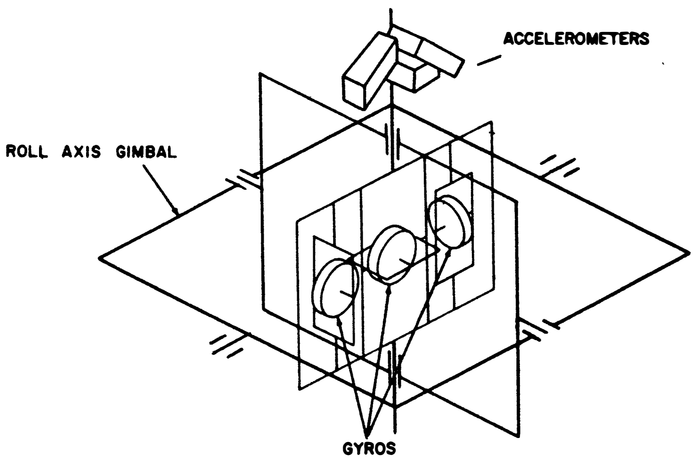


Fig. 1. Platform stabilised for three planes of motion.

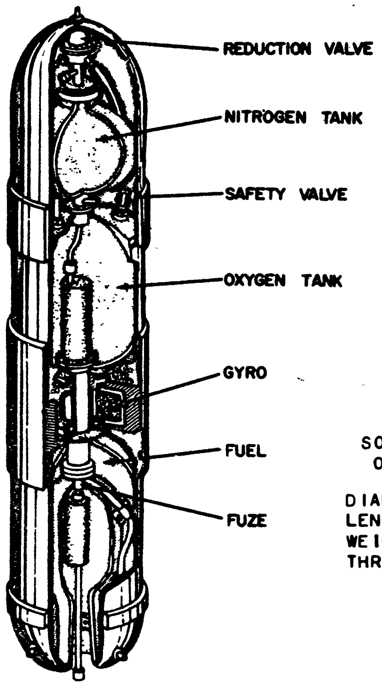
2. EARLY ROCKETS

2.1 A-2 Rocket

The German developed A-2 rocket (Fig. 2) was one of the first rockets using a simply gyro system for guidance. A large gyro was placed into the centre of the rocket between the oxygen and fuel containers. The axis of the gyro was rigidly mounted to the rocket. The gyro wheel coasted freely during the flight; it was supposed to keep the rocket in the correct attitude by brute force. Two A-2 rockets were launched in 1934 from guide towers on the Borkum Island in the North Sea, both soaring to 7000 ft (2000 m). However, it was apparent that such a system had severe shortcomings, as it required a large and heavy gyro, rigidly mounted and thus presenting intercoupling problems between the gyro and the rocket.

2.2 The Goddard Rocket

Almost simultaneously with the A-2 development, the American rocket pioneer R. H. Goddard was working on his first gyroscopically-controlled rocket. He fired it in the spring of 1935. It should be noted that this was the first time that the attitude of a rocket was sensed by a gyro, and the attitude indications were used to operate jet-vanes in



SOME IMPORTANT DATA OF THE A-2 ROCKET

DIAMETER	12"
LENGTH	5-1/2'
WEIGHT	400 LB.
THRUST	650 LB.

Fig. 2. German A-2 rocket.

order to control the rocket. Furthermore, a tilt programme was incorporated to turn the rocket from vertical take-off into horizontal flight. The altitude reached was 4,800 ft (1500 m) and the distance covered was 2.5 miles (4 km).

2. 3 A-3 Rocket

The A-3 series of rockets launched in 1937 were the first missiles to incorporate trajectory control. The complicated guidance system was designed to launch the rocket vertically. The attitude of the rocket was controlled by three rate gyros. Accelerations and velocities were measured in pitch and yaw by spring mass accelerometers and oil damped integrators mounted on a two-axis gyro-stabilised platform (Fig. 3). The principle of this system was sound but it was too complex to be practical with the instruments which could be built at that time. Five A-3 rockets were launched in 1937, but their control system was not adequate to handle the rockets under flight conditions.

2. 4 A-5 Rocket

The A-5 type of rockets (Fig. 4), an improved version of the A-3, used a simpler guidance system. This was a 3-gyro, 3-axis stabilised platform that provided attitude control and a tilt programme. Angular deviations were sensed by rate gyros located above the stabilised platform, and the signals were mixed and fed into a control system also mounted above the platform.

The complete guidance and control system was in one package, as shown in Fig. 5. Connections to the jet steering vanes were made by aluminium rods. The first A-5 missile was launched late in 1939, its guidance system was the forerunner of the one used in the V-2.

2. 5 A-4 (V-2) Rocket

Two different guidance systems were developed for the A-4 missile, later renamed the V-2 (Figs. 6 and 7). The first was the familiar LEV-3 guidance system (Fig. 8). The LEV-3 consisted of two free gyros, control potentiometers, pendulums, servo motors and other components necessary for mounting and adjustment. One of the free gyros controlled yaw and roll deviations while the other controlled pitch deviation and tilt programme. A gyro-type accelerometer

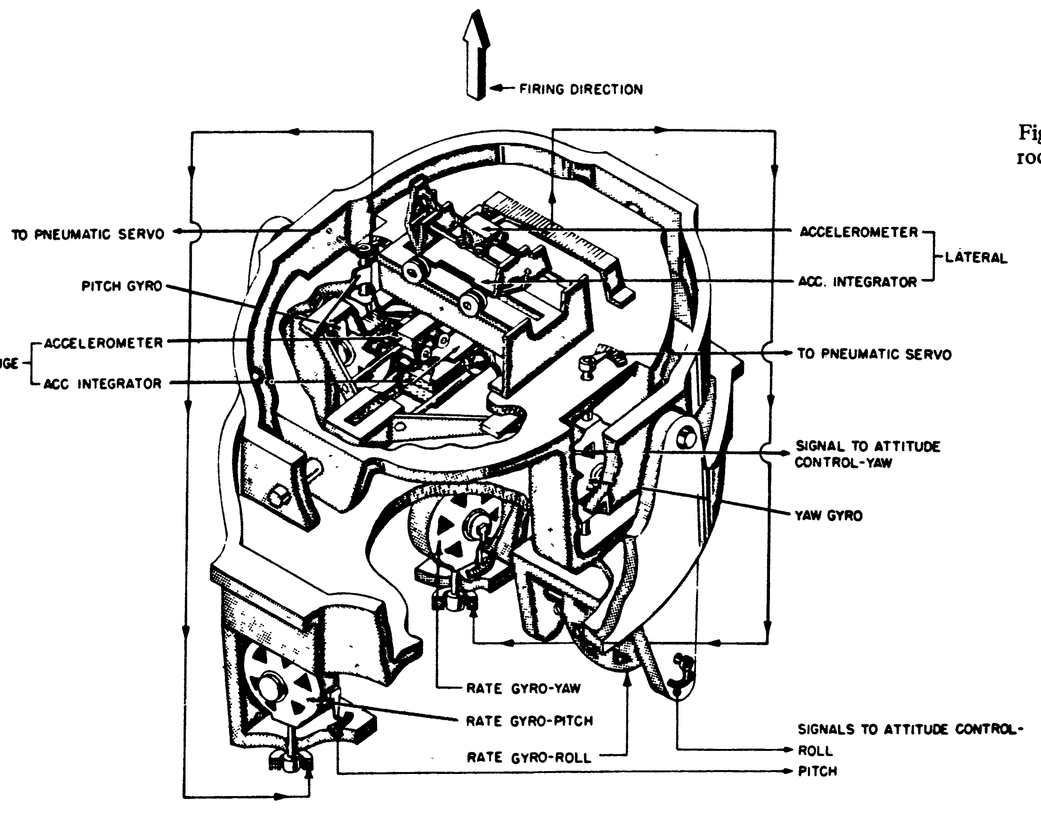
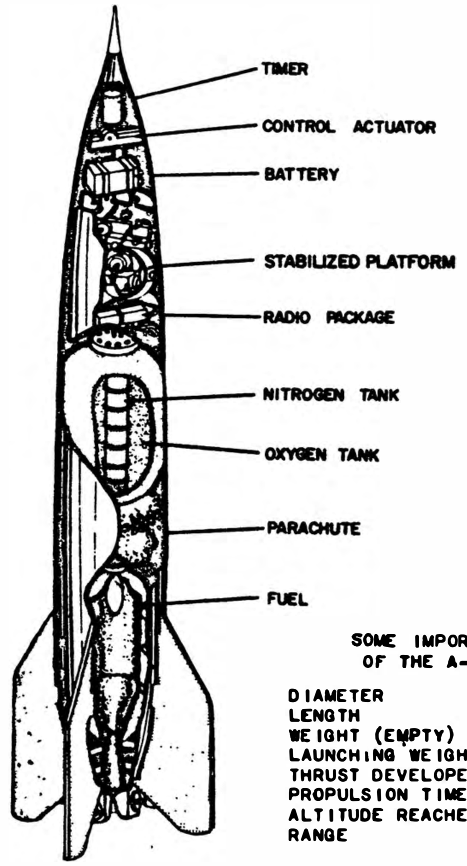


Fig. 3. Stable platform for A-3 rocket.



SOME IMPORTANT DATA OF THE A-5 ROCKET

DIAMETER	28'
LENGTH	22'
WEIGHT (EMPTY)	1,200 LB.
LAUNCHING WEIGHT	1,800 LB.
THRUST DEVELOPED	3,300 LB.
PROPULSION TIME	45 SEC.
ALTITUDE REACHED	13,000 METERS
RANGE	18,000 METERS

Fig. 4. German A-5 rocket.

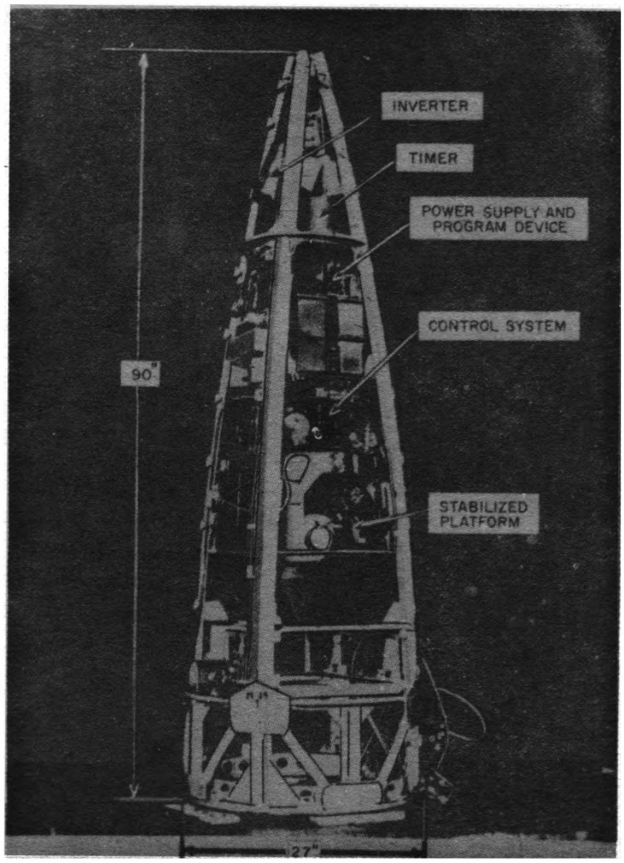


Fig. 5. Guidance and control system for A-5 rocket.

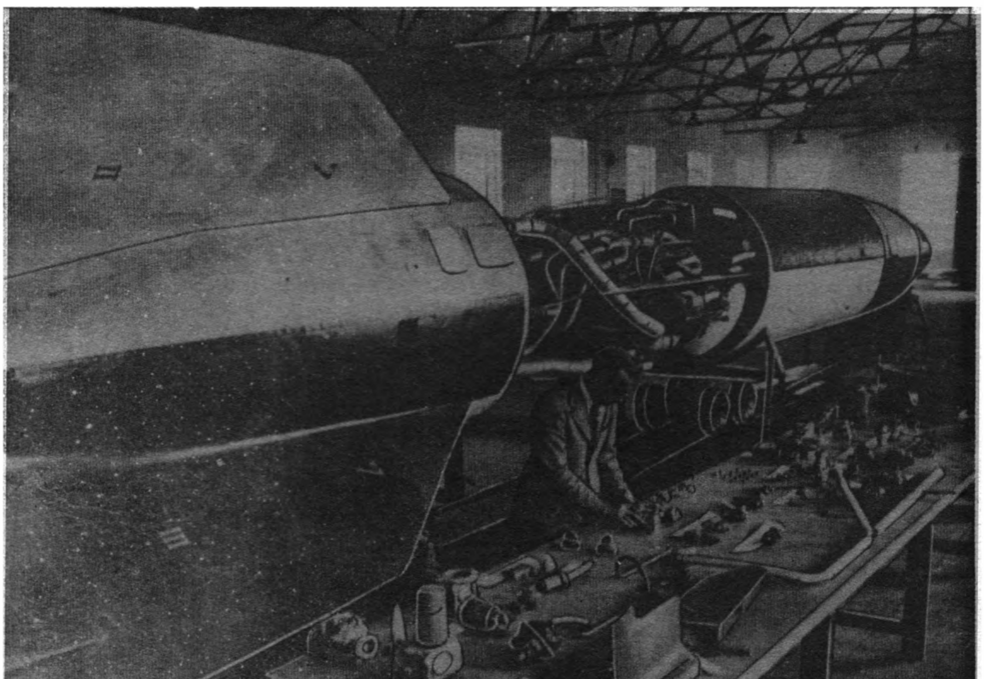


Fig. 6. The major components of a V-2.

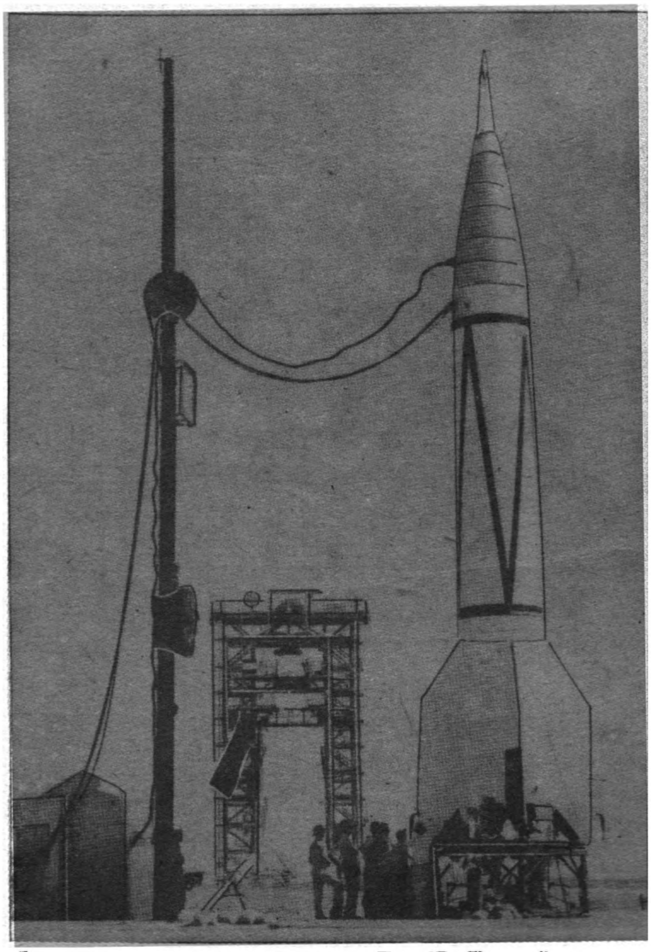


Fig. 7. Preparations for a V-2 launch from White Sands Proving Ground, New Mexico in July 1951.

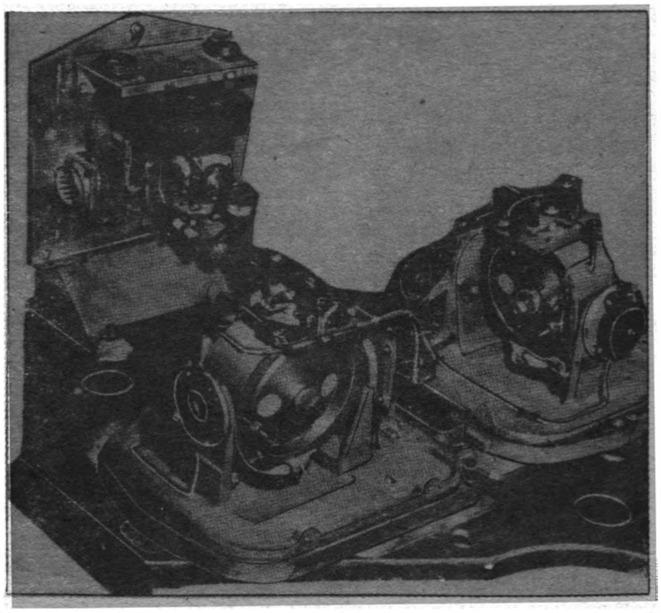


Fig. 8. LEV-3 gyro stabiliser for V-2.

was developed which incorporated a preset device for propulsion cut-off (Fig. 9). This system was straightforward and very dependable. A great many of these missiles were fired with an accuracy of 5 km (3.1 miles) circular probable error (CPE) over a range of 200 km (125 miles). The use of an electronic guide beam for additional yaw control reduced the lateral error to about 800 m (½ mile).

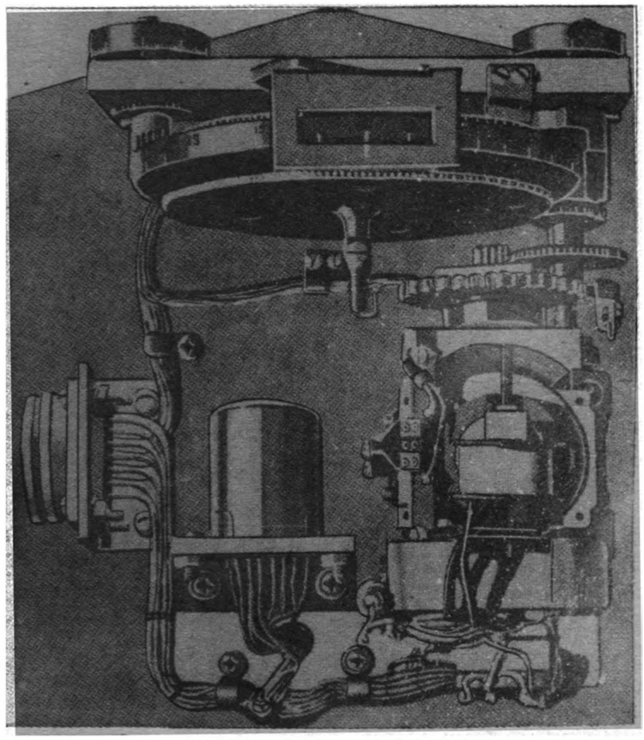


Fig. 9. V-2 propulsion cut-off device, system 1.

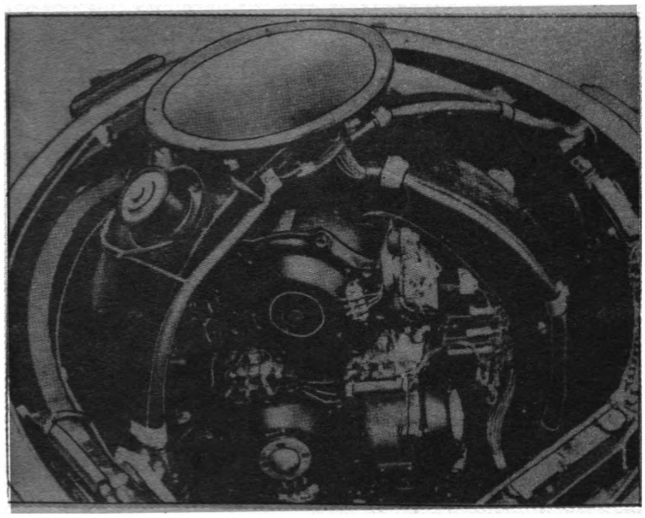


Fig. 10. A-4 (V-2) stabilised platform.

The second system developed for the V-2 was similar to modern guidance systems, but with components not nearly as accurate as those used today. A 3-gyro, 3-axis stabilised platform (Fig. 10), 20 in (50 cm) in diameter and weighing 100 lb (45 kg), was suspended by external gimbals and provided attitude signals and a timed tilt programme. Both an ac and a dc power supply were required for operation of the platform. Servo motors and accelerometers were operated by one- and two-stage on-and-off contacts. Use of gyro rotors with a large angular momentum made the system simple, stable and reliable.

Cut-off of propulsion was controlled by an integrating gyro-type accelerometer coupled to a disk integrator. These were mounted on the stabilised platform along the major axis of the missile (Fig. 11). This device calculated velocity and distance and determined propulsion cut-off time.

Yaw was controlled by an accelerometer consisting of a coil moving in a magnetic field. The integrations were per-

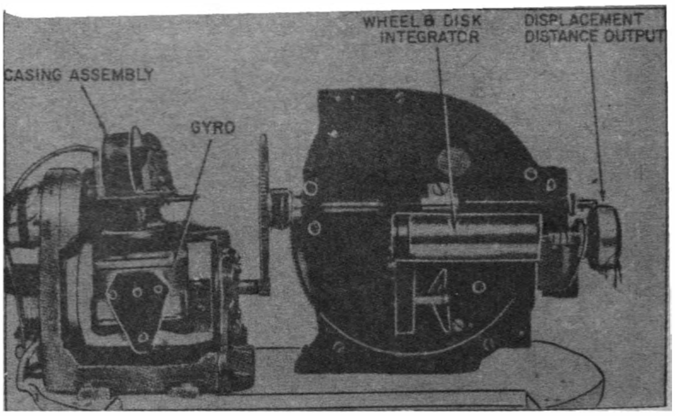


Fig. 11. V-2 propulsion cut-off device, system II.

formed in capacitor networks. Test firings demonstrated a 50 per cent probability that range error would not exceed 4.2 km (2-1/2 miles) and lateral error would not exceed 2.4 km (1-1/2 miles) for a range of 200 km (125 miles).

3. PROBLEMS IN THE DEVELOPMENT OF GUIDANCE SYSTEMS

Although the V-2 guidance system could hardly be said to provide pinpoint accuracy, it did demonstrate the feasibility of inertial guidance. New work in theory, design and manufacturing techniques was required to:

1. Reduce size and weight of components

2. Eliminate friction in components to improve accuracy and reduce reaction time

3. Eliminate shift of centre of gravity due to acceleration

4. Improve reliability and reproducibility of instruments

5. Improve computer and servo techniques

Gyroscopes are mounted in a gimbal suspension to enable them to maintain a fixed orientation in space. The most familiar example is the gyro which keeps a shipboard compass level regardless of how the ship tilts. Such a gyro uses an external gimbal system: the gyro is suspended inside a pair of rings, one of which can move within the other. In the V-2, the weight of the guidance system was reduced by the use of hollow box steel gimbals instead of the conventional solid aluminium alloy rings. This structure also had better resistance to stress, but external gimbal systems are inherently bulky and components are not easily accessible for calibration, maintenance and replacement.

Among the problems which had to be overcome were the following: large accelerations tend to distort the various components as well as the entire suspension of the stabilised platform, especially the external gimbal suspension. These distortions may cause friction between components or a shift in the centre of gravity, and these in turn cause undesirable precession of the stabilised platform.

Early guidance systems had to depend on ball bearings in the gyroscope precession axis. Although in industrial applications the coefficient of friction of ball bearings is considered very small, it is far too great for missile instruments.

Gyroscope drift is the deflection of the spin axis of the

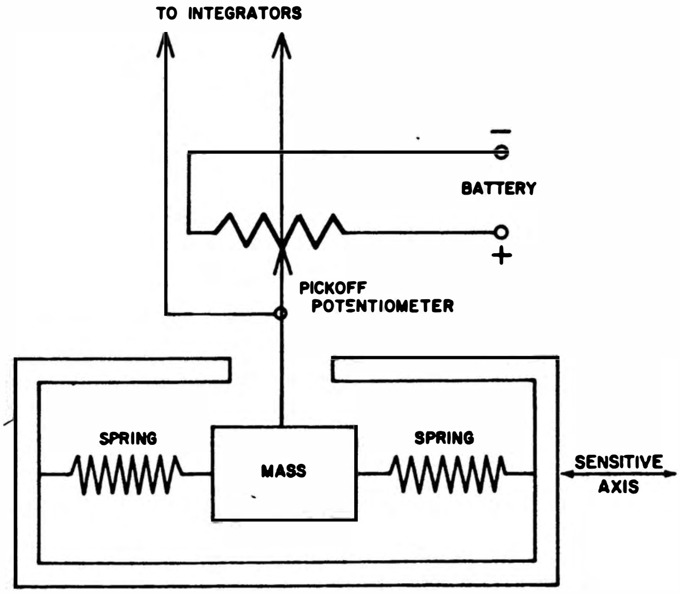


Fig. 12. Spring-mass accelerometer.

gyro from its initial alignment and is caused by bearing friction, shift in the centre of gravity or any other torque about the precession axis. Deflection of the spin axis of a gyro causes the platform to move from its stabilised position, and this in turn causes the accelerometers to measure accelerations in false directions, resulting in guidance errors.

The drift rate of early gyroscopes used on aircraft to indicate attitude and heading was about 10°/hour. The drift rate of gyroscopes used on present missiles is only a fraction of this value, but further reduction of gyroscope drift will be necessary to provide the accurate stabilisation required for future platforms.

Also, in order to achieve high impact accuracy in range direction it is necessary to determine thrust cut-off relative to velocity and the distance covered. This problem was eventually solved by use of instruments which compute the first and second integral of acceleration.

4. EARLY GYROS AND ACCELEROMETERS

4.1 Spring-Mass Accelerometers

A spring-mass accelerometer of the type used in the A-3 missile is shown in Fig. 12. At zero acceleration, the mass is centred by the supporting springs. If the housing is accelerated along its sensitive axis, the weight tends to resist the acceleration and is displaced from the centre to a distance directionally proportional to the acceleration. This displacement is sensed by a pick-off potentiometer which originates a signal proportional to the displacement (and therefore to the acceleration). This type of accelerometer is neither sensitive nor accurate enough for modern missiles which encounter a wide range of accelerations.

4.2 Integrating Accelerometers

One of the problems encountered with the V-2 missile was accurate measurements of velocity and position during flight.

A method of guidance was needed, independent of ground-based reference signals. To achieve proper flight control, the acceleration measurements, which are the basic information

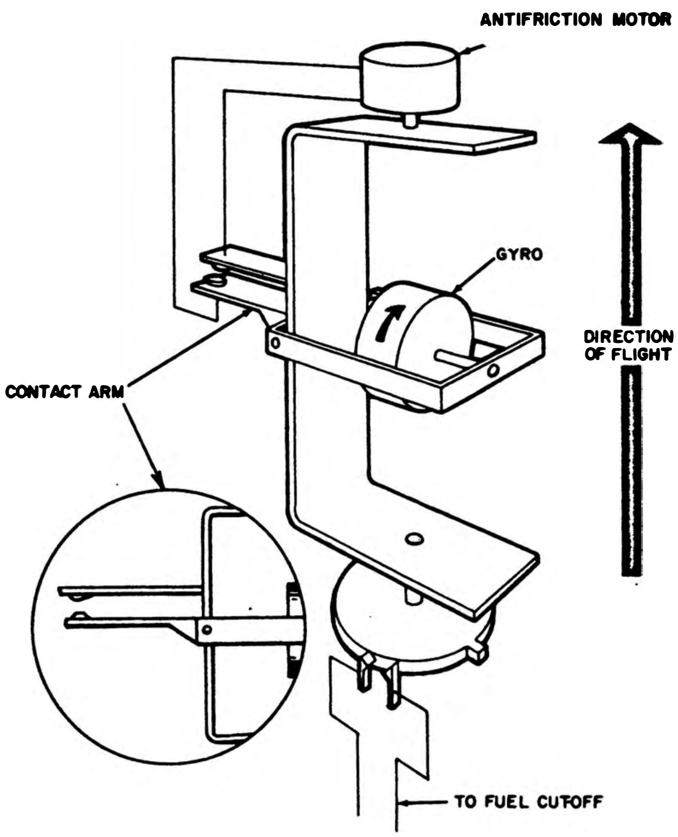


Fig. 13. Mueller mechanical integrating accelerometer.

in inertial guidance, must be integrated.

Several integrating accelerometers were developed for missile guidance, using mechanical, electrical and elecro-chemical principles. These were light in weight and free from jamming.

4. 2. 1 Mechanical Integrating Accelerometer

The first unit to be flight tested was the Mueller mechanical integrating accelerometer, a gyroscopic device shown in Fig. 13. This is primarily a range device to cut off propulsion when the rocket attained the velocity required to reach its target. The gyropscope is supported in an unbalanced position and therefore precesses at a rate determined by the acceleration. The angle through which the gyroscope precesses is a measure of the integrated acceleration, hence of the missile's velocity. This device was very simple and reliable and was used in most of the V-2 flights.

4. 2. 2 Electrolytic Integrating Accelerometer

An electrolytic integrating accelerometer was developed by Buchhold and Wagner. A pivoted arm with a copper slug moving between the poles of two electromagnets unbalances an electrical bridge. The signal obtained is applied to a restoring coil in a magnetic field in series with an electrolytic cell. Current flowing in the coil and cell causes a chemical change in the cell at a rate proportional to the acceleration, and, after an interval corresponding to a predetermined velocity, the cell voltage increases suddenly. This jump of voltage can be used for propulsion cut-off.

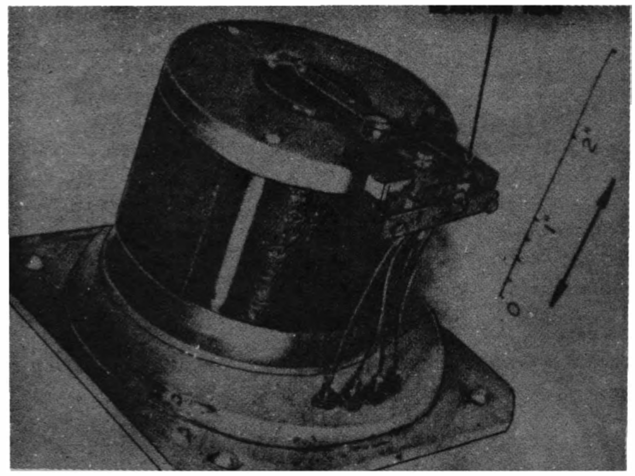


Fig. 14. Schlitt integrating accelerometer.

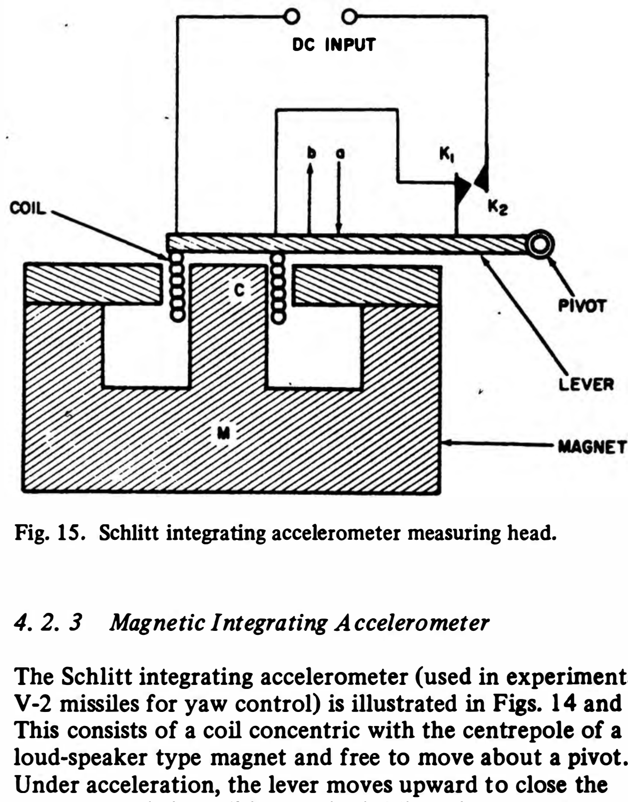


Fig. 15. Schlitt integrating accelerometer measuring head.

4. 2. 3 Magnetic Integrating Accelerometer

The Schlitt integrating accelerometer (used in experimental V-2 missiles for yaw control) is illustrated in Figs. 14 and 15. This consists of a coil concentric with the centrepole of a loud-speaker type magnet and free to move about a pivot. Under acceleration, the lever moves upward to close the contacts, and the coil is energised. When the contacts are closed, the resulting forces cause the coil and lever to move downward, opening the contacts. The average current through the coil is in proportion to the acceleration of the missile. This instrument provides information for one direction only, but use of a bridge circuit gives accurate data for both directions. The current may be integrated once, twice, or three times in a capacitor network to measure velocity, distance, or the integral of distance as a function of time, respectively.

5. COMPONENTS OF PRESENT INERTIAL GUIDANCE SYSTEMS

A missile in flight has no route markers or guide-posts to follow in reaching its destination. Once launched, the missile is on its own and its self-contained guidance system must be able to compute speed, distance, and direction to guide the missile smoothly to its target, regardless of outside

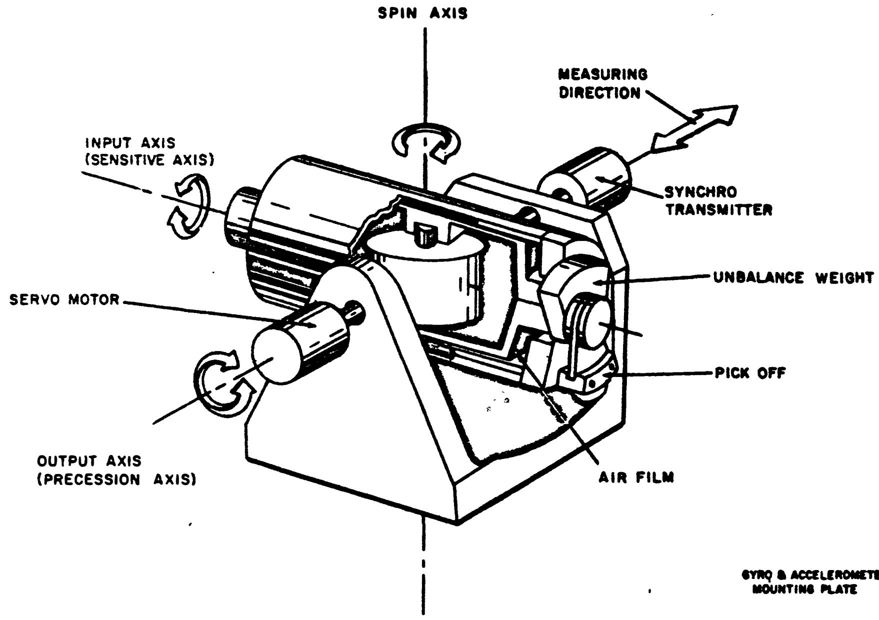


Fig. 16. Air-bearing gyro accelerometer.

disturbances. The high speed of missiles calls for a guidance system which operates continuously and rapidly enough to detect and correct deviations before they seriously affect the trajectory.

To make the required measurements and adjustments, present (i. e. in 1959 – Ed.) inertial guidance systems use accelerameters mounted on a space-fixed platform suspended by a gimbal system. Signals from the accelerometers are evaluated by computer units which transmit the necessary commands to the actuators of the controls.

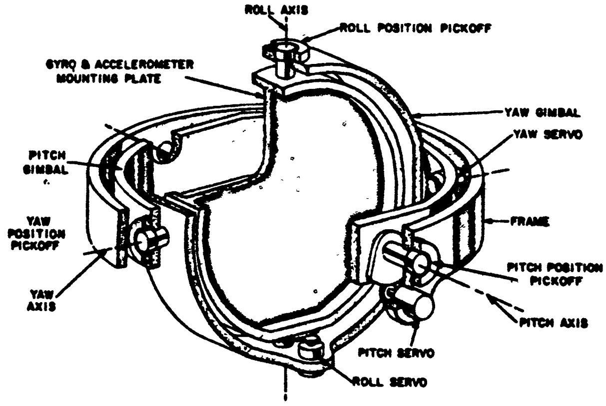


Fig. 17. External gimbal system.

5. 1 Accelerometers

Measurement of accelerations is the key to inertial guidance. The platform is stabilised and aligned to provide the mounting and reference essential for accurate functioning of the three accelerometers which measure changes in motion along the three axes. From these measurements, both velocity and distance can be computed. These accelerometers must be capable of measuring accelerations as small as a few ten thousandths of one g and as large as 10 g. They must be precision-mounted on the stabilised platform with their axes perpendicular to each other. Precise machining, calibration, and good damping are required to reduce the effects of vibration and assure accuracy.

One of the most successful modern accelerometers is an air-bearing gyroscope with an unbalance weight fastened to the inner cylinder. The inner cvlinder is separated from the outer cylinder by an air-bearing (Fig. 16). An acceleration in the direction of the precession axis causes a torque by the unbalance weight around the air-bearing axis. The torque causes the outer cylinder to precess, and the rate of precession is proportional to the acceleration.

The outer cylinder or gimbal is mounted on ball bearings. The friction in these ball bearings causes some precession of the inner cylinder and a corresponding change in the measuring direction of the accelerometer. To prevent this unwanted precession, a pickoff senses relative motion between the two cylinders and sends electrical impulses through an amplifier to a servo motor which is geared to nullify the effect of this friction torque.

In measurement of accelerations, the angular velocity of the precession shaft is proportional to the acceleration. The angular position of the precession axis indicates velocity in the measuring direction. This information, in the form of voltages produced by the synchro-transmitter, is transmitted to the computer for evaluation. The computer in turn sends any necessary commands to the control actuator system.

5. 2 Stablised Platform

The stabilised platform is the reference base for the inertial guidance system. Its position in space is fixed by three gyroscopes with their reference axes perpendicular to each other. Whether on the Earth or in outer space, the platform maintains the same orientation.

In early missiles, the platform was suspended by three concentric, interlocking gimbal rings (Fig. 17). Use of this conventional external-gimbal system in missiles disclosed several serious faults: it proved to be too bulky and heavy, and under the tremendous acceleration of missile firing it was deformed to an extent that accuracy was impaired. Development of a suspension by internal gimbals has made the stabilised platform an accurate and dependable reference base. Figure 18 shows a stabilised platform with its internal gimbals, air-bearing gyroscopes, accelerometers and pendlums.

5. 2. 1 Internal Gimbal Suspension

The internal gimbal system is, essentially, the conventional gimbal system turned inside out. Figure 19 shows the bearings in the centre of the device. The gyros, accelerometers and pendulums are fastened to the outside ring or stabilised platform. The outer ring can rotate freely on ball bearings through 360 degrees, but the inner gimbal can move in yaw

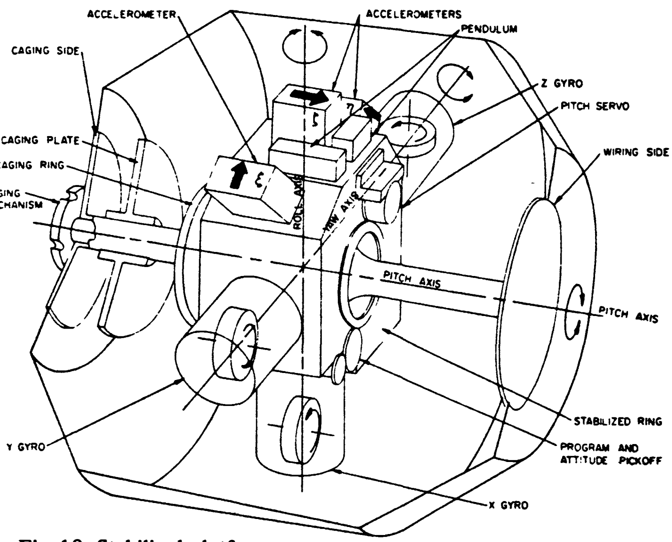


Fig. 18. Stabilised platform.

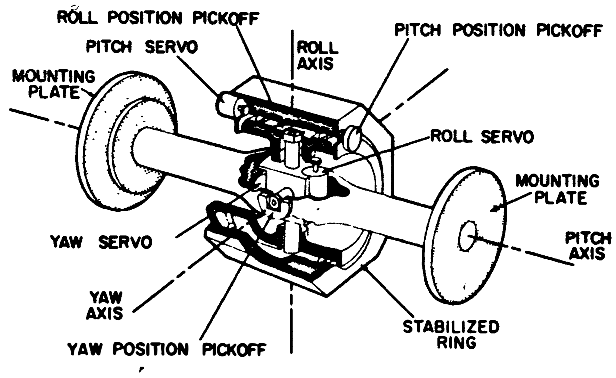


Fig. 19. Internal gimbal system

and roll only through a limited arc (until it touches the outer gimbal ring). The 360-degree rotation allows the missile to be tilted from the vertical about the pitch axis. The limited movement of the gimbals in roll and yaw is sufficient because the missile moves about these two axes through only a small angle before the controls correct the error. Pickoffs and servos are mounted on the gimbals for each of the three axes to measure and correct deviations.

The internal gimbal system has several advantages over the external gimbal system. It saves weight and space and permits the use of more rugged parts. The short, sturdy axles undergo much smaller elastic deformations during missile acceleration and have considerably smaller moments of inertia than gimbal rings in the external gimbal system. Also, instruments mounted on the outer ring are readily accessible for calibration or replacement.

5. 2. 2 Gyroscopes

Three gyros are attached to the outer mounting ring of the internal gimbal system to stabilise the platform: one for each of the three reference axes – pitch, yaw, and roll. Each gyro spin axis is perpendicular to the axis which it stabilises. For example, the pitch gyro is mounted so that its spin axis is parallel to the roll axis and perpendicular to the pitch axis of the missile.

The three gyros are similar. The rotor is mounted on ball bearings within a cylinder which is supported by an air-bearing (Fig. 20). This air-bearing is practically frictionless, making the gyro far more sensitive than those employing

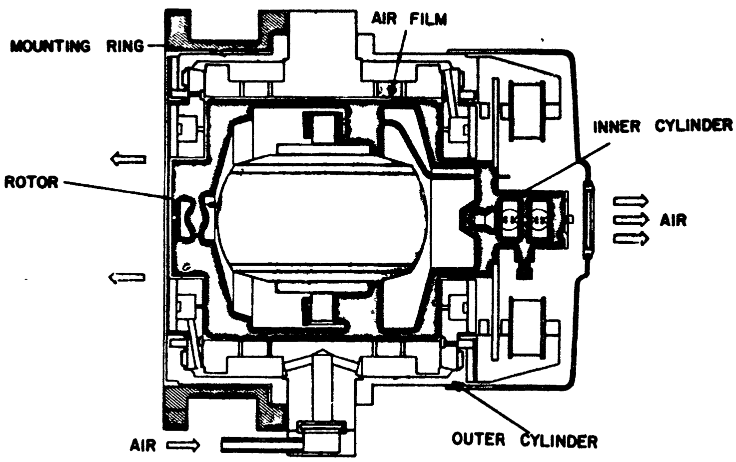


Fig. 20. Cross section through an air-bearing gyroscope.

ordinary bearings and reduces the unwanted precession caused by friction in other types of bearings.

A disturbing torque occurring about the axis controlled by a gyro, causes rotation about the precession or air-bearing axis in proportion to the disturbing torque. Since the rotor is mounted inside the inner cylinder of the gyro, the cylinder undergoes the same precession as the spin axis. This motion is sensed by a pickoff which sends a signal to the servo amplifier. The amplified signal actuates a servo motor which produces the corrective force required to cancel the effect of the disturbing force and return the gyro's spin axis to its original position. The combined effects of the three gyros in maintaining stability about their assigned axes keep the stabilised platform in its space-fixed position so that it can be used as a basic reference to control the missile's flight. By introduction of a programmed flight schedule, the same devices can be used to keep the missile essentially tangent to a precalculated trajectory.

5. 2. 3 Low-Friction Bearings

Before the development of low-friction bearings, missile flights were subject to inaccuracies caused by drift of gyroscopes and gyro-type accelerometers and by inaccurate alignment of the stabilised platforms prior to launching. These inaccuracies were mainly caused by the friction of the conventional bearings then used.

Two different types of bearings have been developed to reduce the friction, both employing a fluid medium to support the shaft. The first type uses a high density liquid to float the precession axis; the second, compressed gas or air.

The liquid type consists of an outer case which seals in the high density liquid and the floating part. The density of the liquid is the same as the mean density of the floating part. Since the part floats freely in the liquid, a pinion bearing is required for axial alignment. While this liquid-type low friction bearing is a great improvement over conventional ball bearings, considerable viscous damping occurs when it is used.

In air-bearings (Fig. 21), the floating part is supported in a manner similar to a ping-pong ball held suspended by a stream of air. The floating part is separated from the housing by a film of air about 0.0015 in (0.038mm) thick. In one type of air bearing, compressed air enters the space between the part and the housing through the air inlet, air chambers, and distribution holes, and leaves through the air outlets.

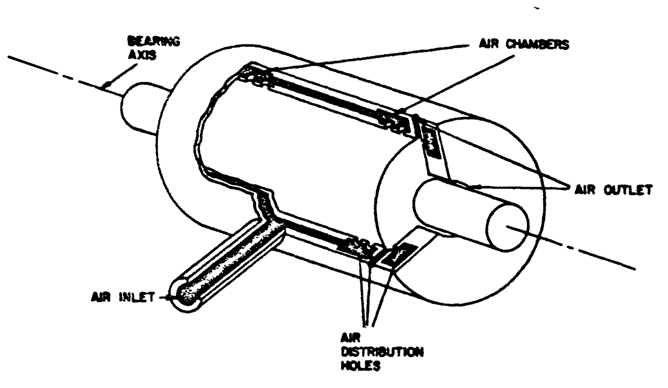


Fig. 21. Distribution hole type air-bearing.

The holes, a few thousandths of an inch in diameter, distribute the air evenly around the bearing to maintain alignment.

Another kind of bearing is presently under development (i.e. in 1959 – Ed.). It is designed as a high speed bearing which would support the spinning wheel of the gyro motor itself. Such a bearing would have considerable friction, but no wear.

5. 2. 4 Pendulums

The accuracy of an inertial system in guiding a missile to target depends in a large measure on the accuracy of pre-launch alignment of the stabilised platform. Precise alignment of the platform involves several factors. The launching site and the target are points on the rotating Earth. But in flight, the inertial guidance system has to be space-fixed. This means that the gyros must initially be set to hold the platform in an appropriate position in relation to the rotating Earth; then, at the moment of launch, they must change their function to hold the platform in a space-fixef reference system.

The coordinates of the stabilised platform must also be aligned with the missile's axes. Furthermore, a missile standing upright on a launching pad sways in the wind and experiences small tremors or oscillations which add to the difficulties of alignment.

For the above reasons, the inertial system is aligned independently of the missile structure, and the two are coordinated at the moment of launch. To handle this task a special type of plumb-line detector has been developed., the air-bearing pendulum, which meets the requirements for extreme sensitivity and also has high zero-pointing stability. Two air-bearing pendulums are mounted on the outer gimbal or stablised platform of the internal gimbal system. These pendulums sense their local horizontal and establish a reference for initial platform setting and calibration. Servo loops, air-bearings, and damping chambers make these pendulums sensitive, quick acting and less susceptible to vibration disturbances than pendulums with other types of bearings.

Each pendulum consists of damping chambers, an air-breathing, and a slug floating in a balanced electromagnetic field provided by a transformer (Fig. 22). When the iron core is centred in the transformer, equal voltages are induced in the two secondary coils at the ends. Movement of the float due to gravity causes an imbalance in the magnetic flux so that unequal voltages are induced. This produces an output voltage proportional to the core movement which is used to initiate a servo loop and return the platform to its proper position.

A precalculated bias voltage, corresponding to the com-

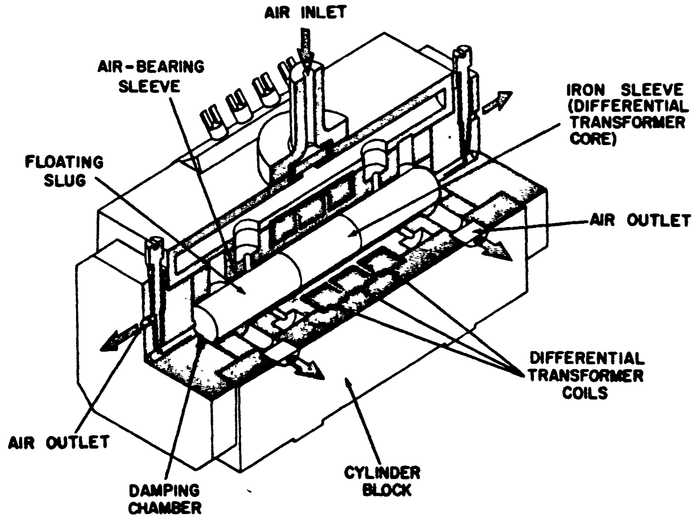


Fig. 22. Air-bearing pendulum.

ponent of the Earth's rotation in the direction of the aligned axis, is added so the pendulum can sense about a null point instead of being constantly in error due to the change in direction of the local vertical as the Earth rotates. This has the effect of slaving the stabilised platform to an Earth-fixed coordinate system until the moment of launch.

At launching, the air-bearing pendulum and Earth-rotation biases are disconnected and the platform becomes space-fixed. As the gyros take over their tasks of resisting angular motion, the pendulums used for alignment of the stabilised platform have no further function.

5. 3 Computers

The function of the computers is to combine the various data from the sensors and compute the appropriate signals to command the flight controls. Sensing instruments on the stabilised platform send deviation data to the computers. The computers evaluate the information from any one sensor to take into account precalculated data, and data from the other instruments. Then, through servo mechanisms, the computers cause the actuators to move the appropriate flight controls to make the required correction.

Computer units are made up mainly of three components: mixer, integrator, and differentiator. Figure 23 shows the relationship of the computers to the other components of an inertial guidance system.

5. 3. 1 Mixers

Mixers combine information from several sensors. For example, course is influenced by crosswinds, missile attitude, and lateral missile speed. The individual sensors detecting these three variables transmit error signals which are mixed together so that each of the variables has a proportional influence on the total corrective movement of the flight control. This mixing is usually a matter of addition or subtraction of sensor signals from the control actuator feedback.

5. 3. 2 Integrators

An integrator computes the cummulative values of variable measurements such as deviation from the planned trajectory,

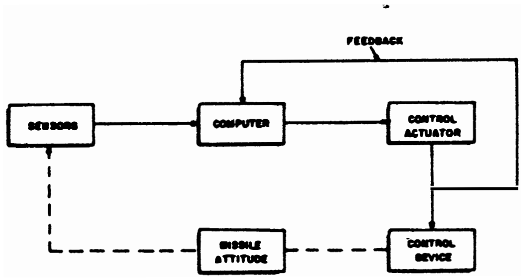


Fig. 23. Schematic diagram of an inertial control system.

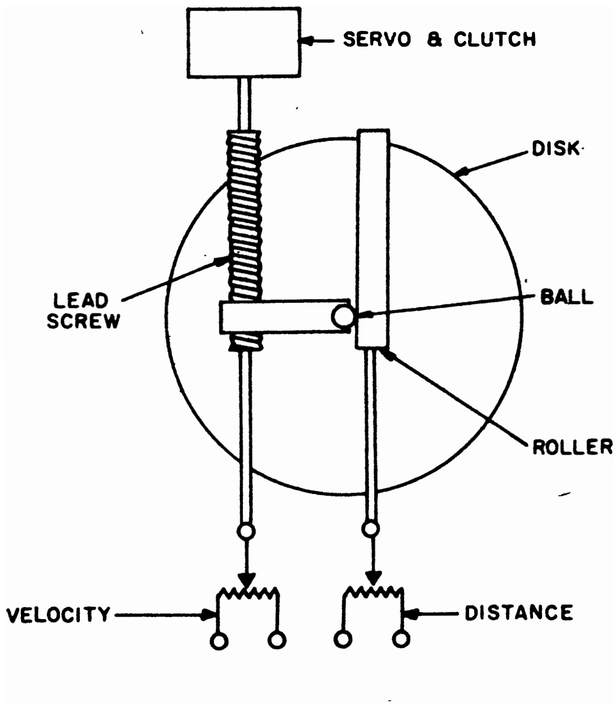


Fig. 24. Ball and disk integrator.

and its output usually goes to a mixer.

Several types of integrators have been devised. Electrical integrators include the thermal integrator, the resistor-capacitor integrator, the resistor- induction combination, the amplifier-resistor-capacitor network, and the variable-speed-motor. Mechanical integrators include the integrating gyroscope and the ball and disk integrator, which are used in most operational guidance systems.

In the ball and disk integrator, a disk is rotated at a constant velocity by a synchronous motor (Fig. 24). The distance of the ball from the centre of the disk corresponds to the input value. The greater the input value, e.g., velocity, the further away from the centre the ball moves, and the faster the ball rotates. A roller in contact with the ball measures the speed of rotation and provides the integrated value. Electrical connections to potentiometers pick off voltages corresponding to input and output values, e.g., velocity and distance.

5. 3. 3 Differentiators

The differentiator reduces the time lag for control operations and therefore improves the stability of the missile in flight. As a sensor transmits information on attitude, velocity, or position, the rate component produces a signal proportional to the rate of change of the input. The rate input signal is mixed with the original deviation signal so that the command to the flight control is correct both for amount and time.

Differentiators may be electronic or mechanical. Resistor-capacitor, resistor-inductance, or resistor-capacitor-amplifier combinations similar to those used as integrators can be wired to produce differentiation instead of integration. The mechanical ball and disk integrator can also be arranged to produce an output proportional to the rate of change.

A special type of gyroscope, the rate gyro, has been designed to produce a rate signal, and this is used in some operational inertial guidance systems. The gyro, restrained by a spring that tends to return the axis to the zero position, precesses a few degrees in one plane as a result of a force on the gimbals caused by movement of the missile. This precession is proportional to the rate of deviation and is transmitted by a pickoff as a rate signal.

5. 4 Actuating Devices

Flight controls are connected by mechanical linkages or cables to actuators such as electrical motors or hydraulic cylinders. The electro-hydraulic actuator system described below is used on most long-range missiles today.

The actuator assembly is mounted in the rear part of the booster unit and consists of two hydraulic cylinders and pistons (Fig. 25). One end of each combination is attached to the missile shell and the other to the thrust chamber which is mounted so it can swivel up and down and from side to side. A pump supplies oil under pressure through a relief valve, an accumulator, and a transfer valve to the control actuators, and back to the oil reservoir. Signals from the computer unit to the solenoid-operated transfer valve direct the flow of oil so that the pistons move in the proper direction. The magnitude of actuator movement is proportional to the volume of oil admitted to the cylinders by the transfer valve.

6. GUIDANCE SYSTEM OF PRESENT DAY MISSILE

Inertial systems are used for the guidance of IRBMs, ICBMs,

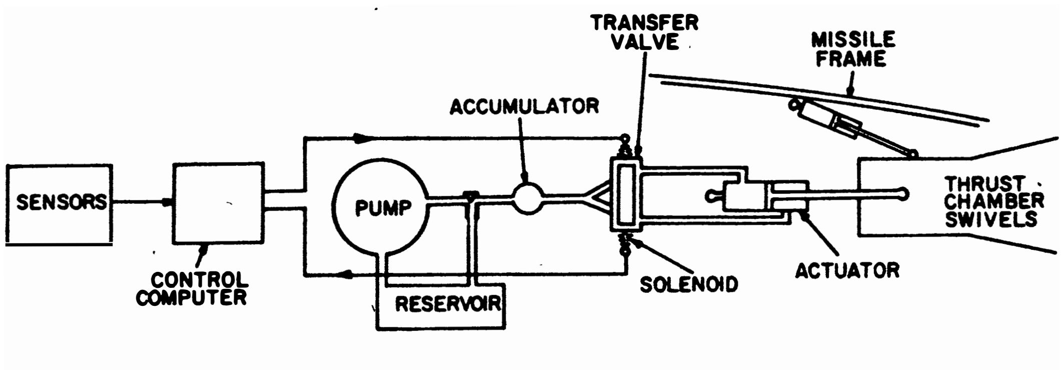


Fig. 25. Electrohydraulic actuator system.

and satellite launchers. Some of the missile systems which depend entirely on inertial guidance are the Redstone, Jupiter, Pershing and Thor. The principal characteristics which make inertial guidance suitable for these missiles are:

1. Reliability and Accuracy – The self-contained inertial guidance systems can guide a missile accurately to the desired target

2. Minimum of Ground Support Equipment

3. Immunity to Jamming – Because the guidance system does not depend on electronic signals from the ground, it cannot be jammed.

The various inertial guidance systems used on these missiles are discussed in the following sections.

6. 1 Jupiter System

The Jupiter is an IRBM with a range of approximately 1500 miles (2400 km). Its inertial guidance, based on the Delta-minimum principle, is used to keep the missile as close as possible to the precalculated trajectory. In many respects the Jupiter guidance system could be considered as a refinement of the second V-2 system, but with tremendous improvements in accuracy, stability and reliability.

The Jupiter inertial guidance is a three-dimensional, modified null-seeking system which continuously compares actual flight path information with precalculated trajectory data. By comparison of the two sets of data, the system senses errors and corrects them by swivelling the engine. The system also provides thrust cut-off and other control signals as required.

Inertial guidance in the Jupiter is based on a space-fixed reference system having three mutually perpendicular axes, each with an associated computer. The gyro-stabilised platform used in the Jupiters is a smaller, lighter and more rugged version of the Redstone platform. The platform with its associated components is illustrated in Fig. 18.

The principal components of the stabilised platform are:

1. A stabilised outer ring which provides a space-fixed reference base for the sensing elements

2. Three air-bearing gyros which sense disturbing torques and maintain the attitude of the stabilised ring

3. Two air-bearing pendulums used to establish local horizontal for initial platform alignment

4. Three air-bearing accelerometers used to sense accelerations of the missile in each of three planes

5. A missile mounting bar, caging plate and ring, and remotely operated caging mechanisms.

The internal gimbal suspension is illustrated in Fig. 19. It differs from previous designs in which the gimbal rings were outside the stabilised parts. The ball-bearing-mounted suspension in the centre of the platform saves weight and provides ready access to sensing components for ease in calibration. The missile can move with respect to the stablised ring. The inner-most gimbal allows movement around the yaw axis; the next gimbal, around the roll axis. The platform can move around the pitch axis, which allows sufficient freedom for the tilt programme. Yaw, roll, and pitch servo motors provide torques to correct platform disturbances sensed by the three gyros.

Pickoff devices, mounted along the three gimbal axes, sense missile attitude deviations, which are sent through three computers for transmission to control devices. These computers are the altitude computer, range computer, and the cross-range computer. The altitude computer nulls any displacement or velocity errors along its axis by pitch control. The cross-range computer aids by providing the yaw control signals. The range computer determines the thrust cut-off point by solving a simple equation which indicates when the missile has reached the right velocity and position to reach the target. Because the thrust decay of the main engine cannot be accurately predicted, cut-off consists of two steps: (1) main engine cut-off, and (2) vernier engine cut-off.

Prior to launch, the stabilised platform is aligned with the local horizon by means of two air-bearing pendulums which sense the local plumb-line. A bias setting is added to the air-bearing pendulum signal to correct for the Earth's rotation. This slaves the platform to an Earth-fixed axis until the moment of lift-off. After launch, the pendulums and Earth rotation bias are disconnected and the platform is kept space-fixed by the three gyros and servo loops.

Platform azimuth orientation is checked by optical means. A prism is mounted on the stabilised ring and a window provided in the missile skin so that the stabilised platform can be aligned with the ground theodolite. After erection of the missile, the launcher and platform are rotated until the theodolite cross-hairs coincide with their reflected image on the prism. Once the platform has been oriented, it is slaved to the theodolite by azimuth signals provided automatically by an autotheodolite. When the missile is launched, these signals are stopped.

In order to take care of wind disturbances during the ascending portion of the trajectory, an angle-of-attack meter is used to sense the direction of the resultant air flow. Signals from this meter are mixed in the computers which provide corrective pitch and yaw signals and cause the missile to head into the wind, thus preventing the development of excessive angles of attack. The angle-of-attack meter is used only while the missile is passing through the high dynamic pressure region.

6. 2 Redstone and Pershing Systems

The inertial guidance systems used on the Redstone and Pershing missiles are similar to that used on the Jupiter, but their components differ in number, size, construction and accuracy. The Redstone system is heavier, bulkier, and less accurate than that of the Jupiter. The Pershing system is much smaller and lighter than the Jupiter system.

6. 3 Systems Used for Explorer Launchings

The inertial guidance system used for Explorer satellite launching vehicles is composed of components for the Redstone and Jupiter systems.

During the booster phase, the missile attitude is controlled by a modified autopilot system. This consists of two free gyros complete with gimbals, control potentiometers, current transfer assemblies, a programme transmitter, pendulums, servos, and mounting parts. The pitch gyro providing the signals for pitch control and tilt programming is, for accuracy reasons, supported on air-bearings. A yaw-roll gyro senses the yaw and roll of the missile. The control potentiometers sense the position deviations of the gyro elements, and signal the missile controls to make the corrections required to maintain the desired flight path.

The missile trajectory is also controlled by electrical signals generated in an integrating gyro accelerometer and timer, for ejection of the upper stages.

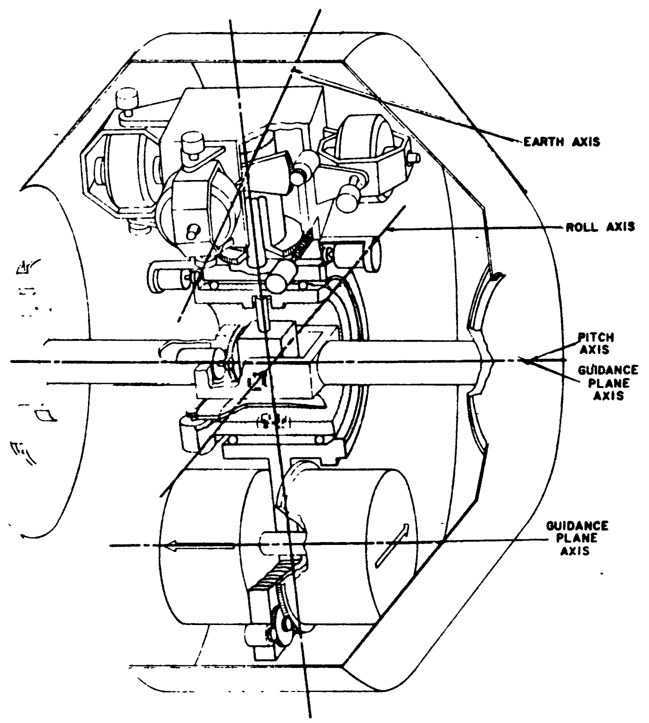


Fig. 26. Stabilised platform for ramjet missiles.

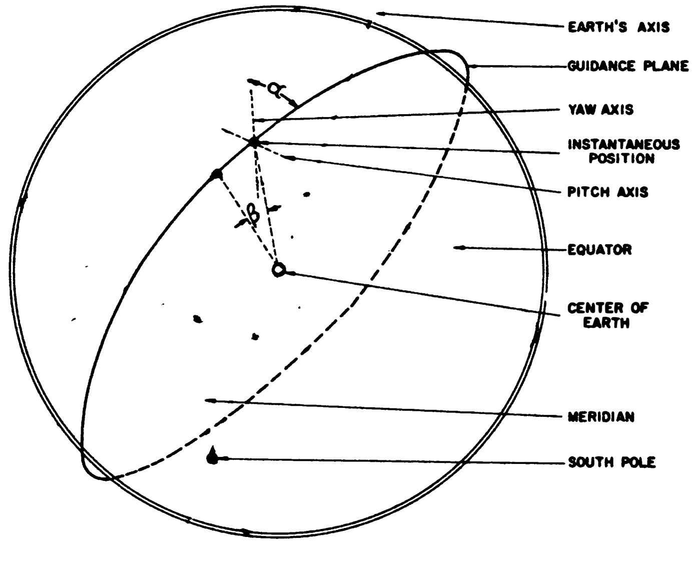


Fig. 27. Earth-fixed coordinates system.

6. 4 Stabilised Platform for a Ramjet Missile

Inertial guidance systems are also used on some ramjet missiles. Guidance problems with this type of missile are greater than with an IRBM or ICBM because the flight time over the same distance is much longer. Large guidance errors may occur, and the ordinary space-fixed platform used in ballistic missiles is inadequate. A transformation of space-fixed measured accelerations into the Earth-fixed system is complicated and difficult to achieve. The use of an Earth-fixed system alone also presents serious problems. Precession of the gyros with respect to the rotation of the Earth requires such a high degree of accuracy that this approach is considered impractical.

A practical solution to the problem is a combination of the space and Earth-fixed reference systems. Orientation and arrangement of the space and Earth-fixed parts is such that only a minimum of computations are required. The composite platform for ramjet missiles, built around the internal gimbal system, is shown in Fig. 26.

The space-fixed gyros and the Earth-fixed accelerometers are mounted on the stabilised platform. The platform is oriented so that its innermost axis, which coincides with the pitch axis of the missile, is always parallel to the guidance plane axis. The position of the guidance plane is determined by the trajectory relative to the rotating Earth and the centre of the Earth, consequently, it is Earth-fixed.

The Earth-fixed accelerometers are rotated around an axis parallel to the guidance plane axis. The angle of rotation (Fig. 27) is determined by the instantaneous position of the missile. This angle is initially set at the launching point and is changed during flight by means of a motor driven by the distance output of the range accelerometer and computer.

The space-fixed gyro part has two additional degrees of freedom. One axis is parallel to the line from the intersection equator-guidance plane circle to the centre of the Earth. The initial angle setting for this axis, α, (Fig. 27) is a constant for a particular flight. It represents the angle between the guidance plane and the meridian plane. The second axis of the space-fixed gyro is kept parallel to the axis of the Earth.

The inertial guidance system uses the accelerometers to perform two basic measurements, one of distance and one of orienting the platform in horizontal position. The accelerometers are mounted on the platform with their measuring planes parallel to the surface of the Earth. One measures in the flight direction and the other, lateral to the flight direction. Both accelerometers directly integrate the accelerations, which means that one of them measures the distance covered. This value is also used by a motor to rotate the accelerometers in the guidance plane axis according to angle β (Fig. 27). The second gives the lateral deviations from the precalculated course. These desviations are reduced to zero by missile control.

The value of Earth rotation is introduced into the system by a clock on the Earth axis or by a synchronous motor. After setting the proper initial values of α and β the stabiliser is aligned and maintained until launch. At the moment of lift-off, the clock on the Earth axis starts and the alignment signals cease.

7. FUTURE OUTLOOK

Since inertial guidance is so successfully used in the ballistic missiles of today, it is highly probable that it will continue to be used in the ballistic missiles of the future. Improvement efforts presently in progress at various development centres will result in even more accurate and more reliable systems. Miniaturisation relating to all components, including wiring and cabling, will produce much lighter and smaller systems with reduced power comsumption. Applications of new materials such as beryllium and fibreglass, etc., will contribute considerably to weight saving.

There is no doubt that inertial guidance will also play an important part in space travel even if its particular role is not seen clearly today. Interplanetary travel will involve long flight times, but propulsion and correction manoeuvres will be executed only during relatively short periods, and the usual guidance errors will be experienced. Consequently, during most of the flight time the errors contributed by guidance will be very small, caused only by minute disturbing effects and friction. Air-bearing guidance components, for example, could be operated as closed self-sustained systems with such low differential pressures that friction and

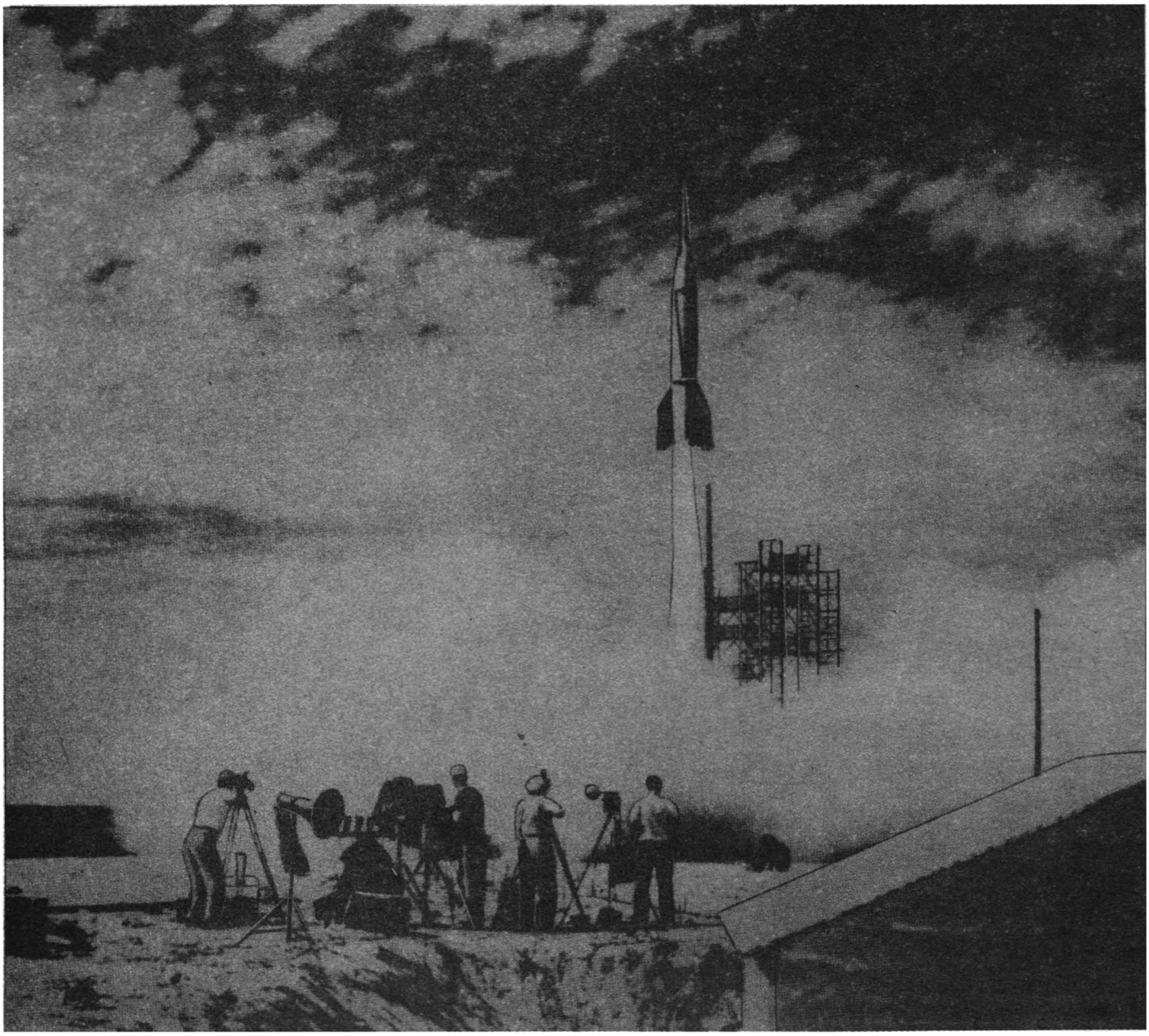


Fig. 28. A V-2 modified to carry an upper stage became the first large vehicle to be launched from Cape Canaveral, on 24 July 1950.
NASA

disturbance torques would be negligible.

Further developments will be aimed towards improving the performance of guidance components during the propulsion periods. For example, cryogenic gyros could feature absolutely homogenous bodies and thus eliminate the main shortcoming of a gyro, the shift of balance. The development of electronic gyros and accelerometers is also aimed in this direction.

Beyond these considerations, it should not be forgotten that space travel, especially manned space flight, will permit supervision and correction of inertial systems by celestial tracking.

In view of the above, while it cannot be predicted today how inertial guidance will be applied, it is certain that it will play a major role in the coming age of space travel.

BIBLIOGRAPHY

Buchhold, T., *Inertial Guidance System of the Redstone Missile (Preliminary Study)*, ABMA Research Report IR-3-P, 7 January 1955.

Finkle, E., *Workhorse of Inertial Guidance*, Missiles and Rockets, February 1958.

Haeussermann, W., *Control Problems of Guided Missiles*, Lecture, 5 November 1954.

Haeussermann, W., *Delta Minimum Inertial Guidance Scheme*, ABMA, Redstone Arsenal, 13 April 1959.

Julian, P., *Inertial Guidance Directs Planes and Missiles*, Radio Electronics, 1959.

Martin, R., *A Servo System for an Air-Bearing Gyro Stabilized Platform*, American Rocket Society, November 1958.

Moore, T. M., *German Missile Accelerometers*, Electrical Engineering, 1949.

Mueller, F. K., *Considerations on Inertial Guidance for Missiles*, ABMA Report No. DG-TM-139-58, July 1958,

Mueller, F. K., *The How and Why of Inertial Guidance*, Missiles and Rockets, February 1959.

Mueller, F. K., *The New Look in Platform Gimbal Systems in Ballistic Missiles.* Missiles and Rockets, March 1958.

Rothe, H. C., *Characteristics of the Air-Bearing Gyroscope.* American Rocket Society, September 1958.

NOTICES OF MEETINGS

Symposium
Theme: **EUROPE-US SPACE ACTIVITIES**

The **1985 Goddard Memorial Symposium,** in conjunction with the **19th European Space Symposium,** will be held at the NASA Goddard Space Flight Center, Maryland, USA on **28/29 March 1985,** organised by the American Astronautical Society and co-sponsored by The British Interplanetary Society in association with other Societies.

Offers of papers are invited. Further information is available from the Executive Secretary and registration forms will be available in due course.

One-Day Symposium
Theme: **SPACE STATIONS**

A one-day symposium on the above theme, considering the technology and applications of Space Stations, will be held in the Society's Conference Room on **17 April 1985.**

Further information and registration forms are available from the Executive Secretary, 27/29 South Lambeth Road, London, SW8 1SZ.

Lecture
Theme: **PLASMA PHYSICS IN SPACE**
by Dr. D. Bryant
Rutherford Appleton Laboratory

To be held in the Society's Conference Room, 27/29 South Lambeth Road, London, SW8 1SZ, on **1 May 1985,** 7.00-9.00 p.m.

Admission is by ticket only. Members should apply in good time enclosing a stamped addressed envelope.

Lecture
Theme: **COHERENT LIGHT FROM SUPERNOVAE**
by A. T. Lawton
President of the Society

To be held in the Society's Conference Room, 27/29 South Lambeth Road, London, SW8 1SZ on **15 May 1985,** 7.00-9.00 p.m.

Admission is by ticket only. Members should apply in good time enclosing a stamped addressed envelope.

One-Day Forum

To be held in the Society's Conference Room, 27/29 South Lambeth Road, London, SW8 1SZ on **Saturday 1 June 1985**, 10 a.m. to 5.00 p.m.

Topic: **THE SOVIET SPACE PROGRAMME**

Subjects will include:

- History of the USSR Luna Programme
- Cosmonaut Update
- Soviet EVA Experiments
- Discussion of Recent Activities

Offers of Papers are invited. Members with a special interest in the Soviet space programme are invited to attend. A registration fee of £5.00 is payable. Forms are available from the Executive Secretary on request, enclosing a stamped addressed envelope.

Lecture
Title: **SATELLITE INSURANCE**
by R. Buckland

Launching satellites into space is a risky business. No commercial project can go ahead without insurance to cover launch and other risks. This talk will describe the role that satellite insurance plays in the development of commercial activity in space.

To be held in the Society's Conference Room, 27/29 South Lambeth Road, London, SW8 1SZ on **12 June 1985**, 7.00-9.00 p.m.

Admission is by ticket only. Members should apply in good time, enclosing a stamped addressed envelope.

Society Dinner

A special dinner will be held at Society headquarters on the evening of Friday **21 June 1985,** to honour the four British astronaut candidates. The cost, including an aperitif, four course meal and half bottle of wine is £18.00 per person; dress informal.

There are only a limited number of places available so early application is essential. Registration forms and other information are available from the Executive Secretary, The British Interplanetary Society, 27/29 South Lambeth Road, London, SW8

Lecture
Theme: **METEORITES: SURVIVORS OF THE EARLY SOLAR SYSTEM**
by Dr. A. L. Graham
Dept. of Mineralogy, British Museum

Meteorites are the most important source of information relating to the early history of the solid matter in the Solar System. They are the only material available for study dating back to the time of information of the planets around 4500 million years ago. This talk will illustrate the variety of meteorites and the significance of the data obtained from them.

To be held in the Society's Conference Room, 27/29 South Lambeth Road, London, SW8 1SZ, England, on **18 September 1985,** 7.00-9.00 p.m.

Admission is by ticket only. Members should apply in good time enclosing a stamped addressed envelope.

36th IAF Congress

The 36th Congress of the International Astronautical Federation will be held in Stockholm, Sweden on **7-11 October 1985.**

Members of the Society wishing to present papers are asked to notify Dr. L. R. Shepherd, Chairman of the BIS International Liaison Committee at Society HQ as soon as possible. Members wishing to present papers at the IAF Student Conference must submit them through the Society.

LIBRARY

The Library will be open to members of the Society from 5.30 to 7.00 p.m. on each of the following dates:
3 Apr 1985, 1 May 1985, 15 May 1985 and 12 Jun 1985.

While every effort will be made to adhere to the published programme, the Society cannot be held responsible for any changes made necessary for reasons outside its control.

ELECTIONS TO COUNCIL

The Report of the Scrutineers on the ballot papers counted up to and icluding 31 January 1985 was as follows:

Number of Papers received 913
Number of spoilt Papers 1

The names of the Candidates and the number of votes cast for each was as follows:

Position	Name	Number of Votes
1	G. V. Groves	802
2	R. A. Buckland	768
3	M. R. Fry	745
4	G. V. E. Thompson	592
5	J. A. Andrews	510
6	F. R. Smith	147

The four candidates receiving the highest number of votes and who were accordingly declared elected were:

G. V. Groves R. A. Buckland
M. R. Fry G. V. E. Thompson

JBIS journal of the british interplanetary society

MEMBERSHIP OF THE BRITISH INTERPLANETARY SOCIETY

Travel to the stars? Exploration of the Solar System? These are both concepts pioneered by the British Interplanetary Society for half a century. The Society is known throughout the world for its forward-looking thinking, its promotion of space exploration and development. Since its formation in 1933, the BIS has become an *international* organisation, with one-third of its membership from outside the United Kingdom. It is more than an astronautical society: it is a network connecting people with space interests *at all levels* all over the world.

Objectives

The main aims of the Society are:

(1) To promote the advancement of space research, technology and applications.

(2) To serve the general community by the interchange and dissemination of technical and other information by means of lectures, symposia, visits and publications.

(3) To promote the work of those professionally engaged in space research, space technology and allied subject-areas.

(4) To discuss national and international activities in space and to formulate forward-looking policies for the advancement of space exploration and utilisation.

Application for membership must be made on the Society's official form, available from the Executive Secretary. Those with specialist qualifications may be elected immediately to the grade of Fellow. Whatever the grade, the appropriate fees must be included at the time of application. These fees allow an applicant to join the Society *and* receive one of the monthly magazines (see below for details). Other magazines and books are available at extra cost. Other membership privileges include the use of the unique space library (at the times regularly published in the magazines) and attendance of the extensive range of lectures, film shows and, at a nominal cost, study courses. The lectures and study courses are presented by leading space experts, while the film shows are always very popular.

Periodicals

The Society keeps in touch with members by two-large-format regular publications: *Spaceflight* and the *Journal of the British Interplanetary Society (JBIS)*, and the twice-yearly *Space Education.*

For those wishing to keep abreast of space activities, *Spaceflight* (first issued 1956) provides essential reading not to be found in any other publication. Present events and future plans are dealt with in news items and major articles. Extensive participation by readers is developed through correspondence, book reviews, personal accounts and histories. *Spaceflight* is not simply a magazine, it is a valuable source of information respected throughout the world.

JBIS holds a unique place in the history of space exploration. It was first issued in 1934 and is now a leading international publication in its field, well recognised for its emphasis on key topics. Many of today's developments were predicted in its earlier pages. Each issue is now devoted to a specific subject area: Space Technology, Astronautics History, Interstellar Studies and Space Chronicle. Special issues are included e.g. on Remote Sensing, Space Communications, Computer Techniques, Space Materials, Orbital Dynamics, etc.

Space Education, first issued in 1981 and published twice a year, is an example of the Society's commitment to education. Articles cover the basics of astronautics to provide an invaluable background to what is going on in space today. *Space Education* is a medium for the dissemination of information and ideas on the understanding and teaching of space topics. It is a vital source of material for teachers.

Books

The Society has now published three highly-popular books of great interest to expert and lay members alike:

Project Daedalus (192 pp) contains 24 papers that summarise the work of a four year study for a Starship Probe to Barnard's Star.

High Road to the Moon (120 pp) records, in about 150 illustrations and text, many of the Society's original ideas and discussions on Lunar exploration in the visionary drawings of the late R. A. Smith.

The Eagle Has Wings (144 pp) traces the development of astronautics in the United States from 1945 to the end of the Apollo era in 1975.

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