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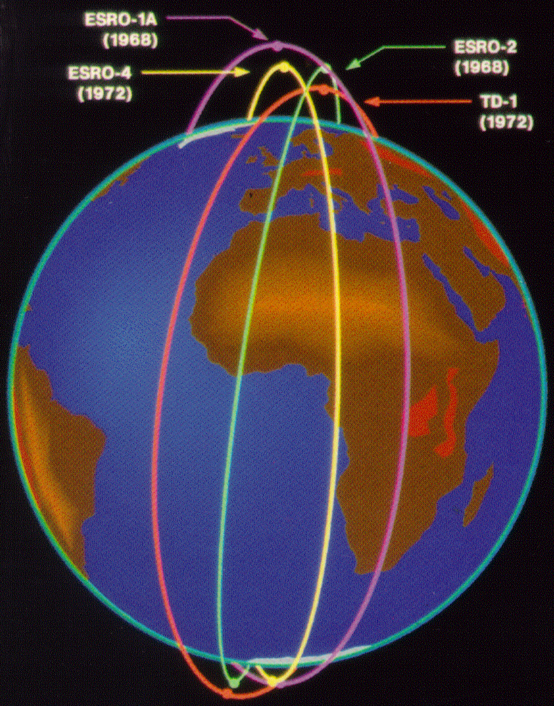
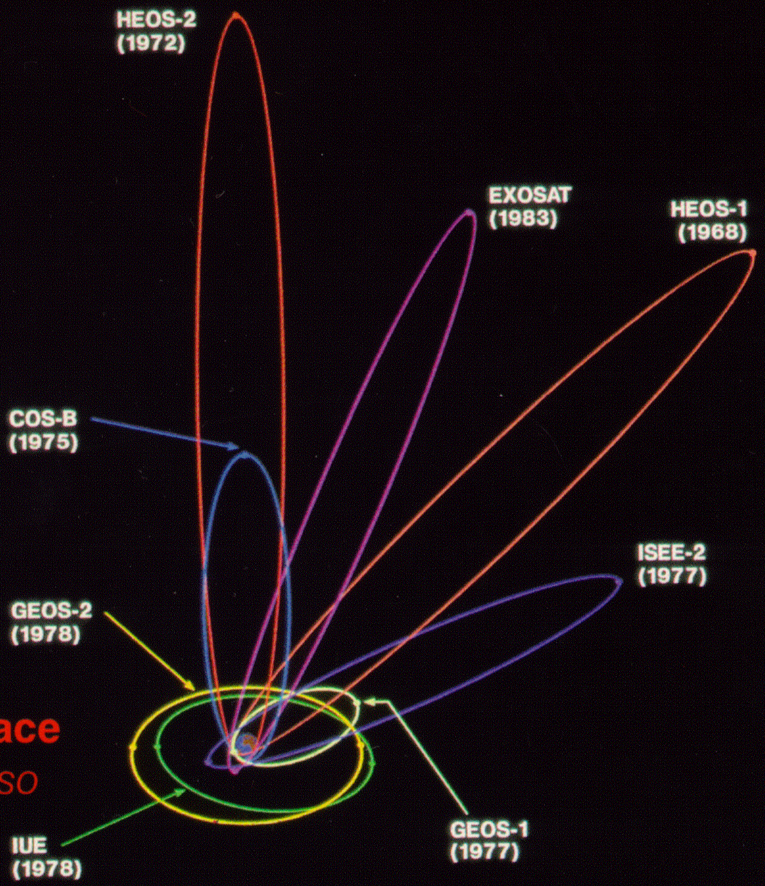
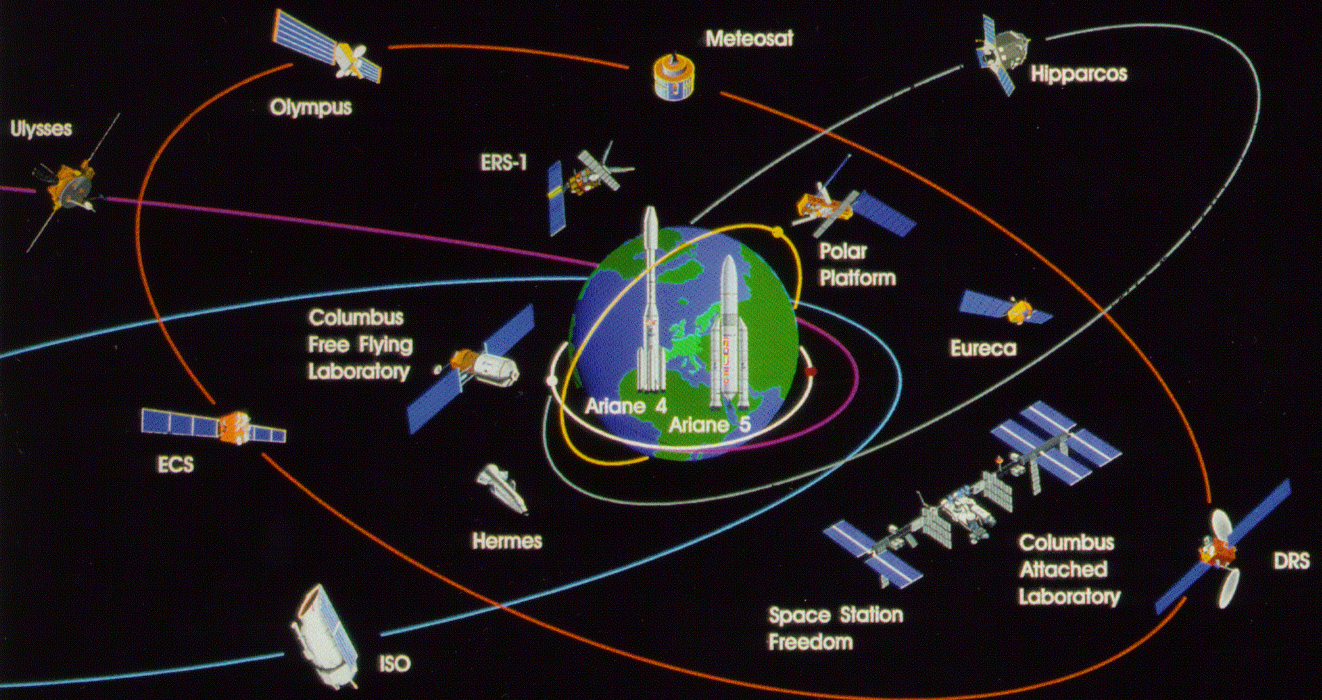




Reflections on Europe in Space

by John Krige and Arturo Russo



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The ESA History Study Reports are preliminary reports of studies carried out within the framework of an ESA contract. As such they will form the basis of a comprehensive study of European Space activities covering the period 1959-87. The authors would welcome comments and criticism which should be sent to them at the appropriate address below.

The opinions and comments expressed and the conclusions reached are those of the authors, and do not necessarily reflect the policy of the Agency.

The ESA History Team comprises:

Prof. M. De Maria, Dipartimento di Fisica, Università di Roma 'La Sapienza', Piazzale Aldo Moro, I-00185 Rome, Italy.

Dr. J. Krige, Department of History and Civilization, European University Institute, Via dei Roccettini 9, I-50016 San Domenico di Fiesole, Italy.

Prof. A. Russo, Istituto di Fisica, Università di Palermo, Via Archirafi 36, I-90123 Palermo. Italy.

The project is based at the European University Institute, where the ESA archives are also housed. John Krige is the Project Leader.

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REFLECTIONS ON EUROPE IN SPACE

John Krige & Arturo Russo

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Foreword

This report brings together four papers in which we have presented some of our work to a wide range of scholarly audiences. Essentially the texts of oral presentations, they were intended to initiate a discussion on these results with people who might have little or no knowledge of European space activities. To do this we naturally had to cast our material in a broader intellectual framework. We also had to make our main points in about half an hour.

These papers created such a lively interest that we have decided to revise them in the light of the discussion that followed their presentation and to circulate them in this series. They are necessarily preliminary, and sometimes polemical. However they do provide people who are interested in the results of this project with some idea of how we think and write when given the opportunity to step back from our archival documents and from the more detailed research that we have been doing, and to reflect on the wider historiographical significance of our research.

Four papers are presented. The first, by John Krige, attempts to think about ESRO in system terms. It is seen as an interlocking network of components including the organization itself, the Member States, industry, and scientists, and the relationships of power between these various elements are explored. The second paper, by the same author, was something of a tongue-in-cheek autocritique of work already done on the launch of ELDO, making particular use of some new results by two of the project's research assistants. Two papers by Arturo Russo then follow. One details the emergence and development of ESRO's telecommunications satellite programme in the late 1960s and early 1970s, placing it in the context of the laborious process that led to the definition of a comprehensive European space policy (including science, applications and launchers) and to the birth of ESA. The other uses the results of an interview programme which we are conducting on the Giotto Halley probe to reflect on the meaning of the term 'big science' in the field of space research.

We hope that our readers find these papers as interesting as did the audiences who heard them.

The European Space System

John Krige

Discussion paper given at the Rathenau Summer Academy 1993 "Ordering the Human-Built World — Die Gestaltung der wissenschaftlich-technischen Welt", Berlin, 26-30 July, 1993

The European space system is that complex of institutions, artefacts, national and international networks, production facilities and commercial activities, which have been built up over the past three decades through a collaborative European presence in space. Its outputs include satellites, sounding rockets and launchers, scientific results, satellite photographs, and telecommunications linkages, scientists and engineers with their embodied technical and managerial expertise, and an ideology which links the conquest of space with industrial progress.

The historic core of this system consists of two organizations officially set up by European governments in 1964, ESRO (the European Space Research Organization) and ELDO (the European Launcher Development Organization). After a shaky start, ESRO enjoyed considerable success in launching sounding rockets and in placing scientific research satellites in orbit. In parallel, from the mid-1960s onwards, it played an increasing role in design studies of applications satellites, notably for telecommunications. ELDO, for its part, dedicated to building a three-stage heavy launcher, failed in a decade to put a single satellite in orbit, and was finally liquidated in 1973. A new organization, ESA, the European Space Agency, was established in 1975. Originally set up to combine the activities of ESRO and ELDO, ESA today has about 1900 staff, and an annual budget of some $2 billion.

ESA inherited from ESRO a headquarters building in Paris, a payload engineering unit (ESTEC, the European Space Technology Centre) in Noordwijk in the Netherlands, a mission control centre (ESOC, the European Space Operations Centre) in Darmstadt, and a small documentation centre (ESRIN) in Frascati near Rome. It also took over a launch base in French Guyana and a globally dispersed satellite tracking network. The bulk of its staff (1150) are based at ESTEC.

The European space system as thus defined has four specific and tightly interrelated characteristics. Firstly, for the governments who funded it, space was a domain of strategic significance. Space activities were not simply, and certainly not primarily, focussed on disinterested scientific research. They had important connections with commercial, military, and prestige considerations. Priorities not only had to be set *within* in each sector (one large astronomical satellite vs several smaller, less complex satellites; meteorological vs aeronautical satellites) but *between* the different sectors science, applications and launchers and, eventually, manned space flight.

Secondly, given its strategic importance, some major powers were determined to develop national space programmes of their own in parallel with a collaborative space effort. There was no question (as in high-energy physics) of subordinating the national to the European programme. On the contrary, European collaboration was *an option*, not a "necessity". The questions Why have a *European* space programme? and, *if* we have it, What should its scope and priorities be? were repeatedly posed in the late sixties and early seventies, and the possibility of replacing a broadly-based multinational effort with bi- and multilateral arrangements was seriously debated.

Thirdly, space policy was an arm of industrial policy. Governments invested in space because they saw it as a way of improving the competitiveness of their industries in key sectors of advanced technology. The nuclear was the favoured candidate for government R and D expenditure in the 1950s; space replaced it in the 1960s. Indeed the launch of ESRO and of ELDO was just one aspect of a major effort by European governments in this decade to build a strong presence in the aerospace sector, an effort which included the Anglo-French decision to build Concorde, and the launch of Airbus Industrie.

Finally, the European space system was not a closed system. It was rather a dynamic and unstable system, a system subject to crosscurrents which originated outside it but which could profoundly affect its path. In particular its trajectory was shaped by political developments "at home" and by technological developments abroad, above all in the USA. Space programmes take years, even decades to evolve, and as such are prey to short-term fluctuations in political climate. The commercial applications of space, moving as they do along the frontier of advanced technology, require that governments repeatedly reassess the applications programmes that they have, or want to embark on. Indeed the main objectives of the European programme were dramatically re-evaluated beginning in 1965 when the US satellite *Early*

Bird demonstrated the feasibility of telecommunications by satellite, so opening up an entire new field of immense commercial and military potential.

Granted the frequent re-orientation in the priorities of the system, I have chosen to concentrate my discussion in this paper on the first decade of the European collaborative space programme. In particular I have focussed on the system articulated around ESRO. This organization, originally set up to do science, was rapidly transformed into something very different from what its scientific pioneers had foreseen, and it laid the foundations for the establishment of ESA. My aim is to throw into relief the network of relationships between the main actors who constitute together the "ESRO system": scientists, member states' governments, industry, and the organization's management.

The ESRO system

Formally speaking the structure of ESRO was very similar to that put in place at CERN. The governing body was the Council, which was made up of two representatives from each of the (ten) national governments who were members of the organization. Its main task was to ensure that the Director General and his staff implemented the scientific programme paying due regard to the financial limits and industrial policies imposed by the member states. For this purpose the Council was advised by an AFC (Administrative and Finance Committee) and an STC (Scientific and Technical Committee). The STC in turn received proposals for missions and for the scientific payloads to be flown on them from a Launching Programme Advisory Committee. The LPAC's task was to combine the suggestions coming from a number of ad hoc expert groups, each dedicated to a different field of space science, into a scientifically coherent and financially reasonable package. That granted there are number of features about the distribution of power in this complex linking the scientific community, the organization, and the member states that deserve special mention and which indeed had unanticipated and sometimes perverse effects.

The scientists and the organization

The scientists (with the support of the member states) saw ESRO as a *service* organization. In particular they were emphatic that it should not be allowed to build up an inhouse scientific staff which could compete with national institutes and universities. The scientific instruments to be flown on a satellite were to be built "at home" with funds especially made available for that purpose by national funding bodies. ESRO's staff, by contrast, predominantly engineers, were not to engage in scientific but in managerial tasks. Normally they would not have an instrument on a payload. They were there to coordinate the various national teams who were building such instruments, and to supervise the integration of the payload into the spacecraft, which was built by industry.

European space scientists had two considerations in mind when defining this division of labour. Firstly, possibly with CERN in mind, they feared that a strong inhouse staff would rapidly become a privileged elite with better resources than national teams, and so able to dominate the shape and content of the scientific programme. By controlling the size and powers of that staff they hoped to decentralize and to democratize experimental opportunities and know-how. Secondly, they wanted to retain the possibility of flying their instruments on spacecraft built *either* by ESRO *or* by NASA *or* within the framework of national programmes. As early as 1959 the Americans had offered to enter into bilateral arrangements with any European scientific groups who wanted to put payloads in orbit with US launchers. The major European powers also had important national space programmes of their own, sometimes involving the construction of their own launchers. By financially and institutionally decoupling the building of the payload from the building and launching of the spacecraft, the scientists sharply increased the options available to them for doing research. This was all the more important in a field where relatively few scientific spacecraft were in fact launched, and in which it could take a decade (or more) to transform a proposal into an orbiting experimental package.

This determination to protect their autonomy, and to ensure that ESRO did not dominate the European space research effort, weakened the scientists' control over the transformation of the organization away from science which began in the mid-1960s. Two reasons led to this perverse effect. On the one hand, the engineers at ESTEC, reduced to a service role, and starved of the possibility and challenge of defining and developing "their" spacecraft and payloads, enthusiastically welcomed the orientation of ESRO's mission towards application satellites. Here was an activity in which they would not be at the scientists' behest, in which they could take a leadership role and flex their professional muscles. This desire inhouse to build a strong capability in the field of applications, was reinforced by the simultaneous determination of some member states, notably France and Belgium, to restrict ESRO's scientific research activity as much as possible. It was not necessary, they argued to pursue this collectively at the European level; national programmes, along with bi- and multilateral arrangements were sufficient. Ironically then, by the end of 1960, the scientists who had insisted that ESRO have no scientific programme of its own — in the interest of building a broadly-based European capability — found themselves supported by inhouse engineers and managers, and by some member states — who were determined to centre the European space effort not on science but on applications! Instead of science being the main priority of ESRO, as the pioneers had hoped, within two decades it was reduced to a mere 10% of the budget. And the scientific programme was made mandatory (cf below) — not because of its popularity, but precisely because it was feared that otherwise not enough member states would contribute to it to make it worthwhile.

The organization, the Council and the member states

A second noteworthy feature of the complex of power relations that we are considering was the steps taken by the member states to maintain a tight grip on the affairs of the organization, particularly regarding ESRO's budget and its relationship with industry. Recognizing that costs in a field of advanced technology would necessarily escalate, the governments who founded ESRO were determined not to find themselves having to negotiate with a management (and a Council!) that came back year after year to plead for more money. Refusing to make an exception for an international body, and treating ESRO just like any national research facility, they demanded that the programme be adjusted to the available resources, that the scientists and the management set priorities. To achieve these objectives the member states built a set of tight safeguards into the ESRO convention and its financial protocols. Firstly, they laid down an overall budget ceiling for the first eight years of the organization's official existence (1500 million New French Francs in 1962 prices, or some $306 million). Then they stipulated that, within that envelope, there would be three-year ceilings determined by the Council voting unanimously. Finally, the annual budgets would have to be phased within the agreed three-year limits, and were to be adopted by the Council by a two-thirds majority. By legally introducing the notion of ceilings, and by insisting that major financial decisions were taken unanimously, each of the countries who founded ESRO introduced powerful safeguards against the organization's costs spiralling out of its control.

It was the British who spearheaded the demand that ESRO evolve within this financial strait-jacket. No member state opposed them. The reason explicitly given at the time was that governments did not want a repeat of the situation that had arisen at CERN. Indeed the British proposals for the embryonic ESRO were negotiated in parallel with a bruising conflict over the financing of the high-energy physics laboratory. The UK Foreign Office, frustrated by the apparent impotence of its delegates to control the laboratory's escalating budgets, had proposed that governments agree on a ceiling for its expenditure among themselves, so bypassing their representatives in the Council. The British were forced to retreat, outmanoeuvred by the combined forces of the management, who wanted as much money as they could get, and a clique of civil servants and scientific statesmen at the core of the Council, who jealously guarded their authority and relative autonomy vis-à-vis national state bureaucracies. The ESRO convention reflected the UK's determination never again to be at the mercy of cost overruns in an international scientific and technological body. And to limit the powers of a Council all too easily prone to identify more with the interests of the organization (as defined by its management) than with the interests of the states they "represented" (as defined by national bureaucracies). Governments also learn!

Industry, the Council and the member states

The ground rules for managing ESRO's relationship with industry were hammered out over the first five years of the organization's life. They were articulated around the notion of just return — namely, the idea that, if a member state contributed x% to the budget of ESRO, x% by value of the technically interesting contracts placed by the organization in European countries should be awarded to its national industries. (The ratio of the latter to the former, of contracts awarded to contribution paid, is called the return coefficient.) In practice this policy proved difficult to implement, because of the uneven development between countries in the relevant sectors of European industry and because of the limited nature of the scientific programme (on average ESRO launched only one satellite every two years). The favoured means of redressing the imbalance was to encourage firms to form consortia in which some technically challenging tasks were allocated to companies in "less developed" or, at least, previously marginalized member states. To stimulate this process the consortia were informed that, all other things being equal — or roughly equal —, a contract would be awarded to that bidder whose profile of companies best served ESRO's aim to achieve return coefficients of unity for all its member states as soon as possible.

For its participating governments then ESRO was not simply an organization dedicated to science. It was also an organization dedicated to the development of space technology and technical know-how in European firms. This latter function dwarfed the former in the eyes of the member states. It was not enough to fly successful scientific missions. If national industries were not at the same time building up inhouse capabilities in key technological sectors and in project management, the organization was failing in its objectives. Return coefficients were the indicators used by the AFC and by the Council to assess ESRO's performance in this regard. By the mid-1960s France had a return coefficient of about two, Italy's coefficient was about 0.75 and Spain and Denmark's coefficients were between 0.3 and 0.4. The poor performance of their industries led these latter three countries repeatedly to reassess their relationship to the organization, and indeed had dramatic consequences. Spain threatened to leave ESRO in 1968, as did Denmark in 1970. And in 1968 Italy, concerned about its low return coefficient and furious about major cost overruns on a satellite pair in which its industry had very little participation, unilaterally refused to finance this part of the programme. The Italians thus created a precedent for what was later to become standard practice — the development of optional programmes in which only those member states who wished to participate were required to do so (see below).

The importance which member states attached to securing a "just return" on technically interesting contracts derived from two sources. Firstly, the need to improve the competitiveness of their high-technology firms. In the 1960s some government began to question the assumption, more or less entrenched since World War II, that scientific research, technological development and economic growth were "naturally" linked together (the so-called linear model). Instead, they felt, a long-term industrial policy was needed in which the state played an active role (e.g. through R and D expenditure and government procurement) to stimulate key industrial sectors. Membership of ESRO was one component of this strategy. It was intended to be an avenue through which governments channelled resources into strategically important national industries. Correlatively, if their contributions to the organization were, effectively, being used to finance such industries in their competitors in the European market (i.e. if their return coefficients were below unity) they quickly applied whatever pressure they could to have the situation remedied.

Behind the governments lay the industrial lobbies. The development of advanced technology required long-term, high-risk investments which most European firms were not willing to undertake without being given suitable guarantees by the state. From their point of view international organizations like ESRO (and ELDO) had the advantage that governments were locked into a structure from which it was extremely difficult to withdraw and in which commitments to fund projects to completion were mutually undertaken. Even if the civilian sector of space was only a small part of the business of, say, the aerospace industry, when conducted in the framework of ESRO it provided just the kind of guarantees that firms like Hawker-Siddley Dynamics in the UK, or Matra in France, or Messerschmitt-Bölkow-Blohm in Germany needed for developing new, sophisticated technologies, technologies which could be transferred between programmes. Indeed it is striking that one of the key arguments advanced inside ESRO in 1968 for funding the scientific satellite GEOS (to be used for exploring the properties of the magnetosphere) was that the technologies developed for the platform could be transferred between it and a telecommunications satellite in geostationary orbit.

The member states (Ministers) and the Council

The determination of the members states' governments to keep a tight reign on ESRO — and on the Council's powers — meant that major changes in programme, and notably those involving additional expenditure over and above the ceilings agreed on in the convention, required recourse to a higher authority. So too did a decision whether or not to continue with the collaborative European space effort after 1972. In terms of the initial agreements any state which so wished could automatically withdraw from ESRO after the first eight-year period. This need to bypass the Council of ESRO (and indeed of ELDO) was reinforced by the conviction, which took root in the mid-1960s that Europe had to define a coherent space policy. As the potential of satellites for meteorology, for maritime and aeronautical navigation, for television and telephonic communications opened up, so European governments felt that they needed to set their priorities between launchers, applications satellites and scientific satellites. These were decisions of such gravity and of such long-term importance that they could only be taken at Ministerial level. Thus from the mid-1960s to the early 1970s the Council's of both ESRO and ELDO found themselves hostage to decisions and policies being thrashed out at the highest level in what became known as the European Space Conferences.

Two features characterized the debates at this level. Firstly, the *deep and divisive difference in priorities* between the member states, notably on the question of whether or not Europe should develop its own launcher. The leading protagonists here were the British, on the one side, and the French on the other. For the British, and particularly Harold Wilson's Labour government which was in power from 1964 to 1971, the development of a launcher was only defensible if it could be shown that the rocket would be commercially viable — and obviously it would not. Far better then, they said, to rely on the United States to put European satellites in orbit. For France, strongly supported by Belgium and by Germany, the prime aim in producing a launcher was not commercial. It was rather to build up technology, know-how and management skills and to guarantee European autonomy in space. Unlike the British, the French in particular were convinced that the US could never be relied on to launch commercially competitive satellites. It was incoherent, they said, to embark on a European telecommunications satellite programme without being absolutely certain that one could put the spacecraft into orbit.

Obviously both of these positions were deeply rooted in the wider political strategies of these two countries. The Suez debacle notwithstanding, the Britain of the 1960s was still the Britain believing in, and hankering after, a "special relationship" with the United States. The France of the 1960s was the France of de Gaulle, with his suspicion of "les Anglo-saxons", and his determination to develop an independent "force de frappe", including of course ballistic missiles. The Britain of the 1960s was also a Britain which, having initially stood aloof from the formation of the Common Market (and even having tried to torpedo it by the establishment of the EFTA), now made repeated applications for membership — only to be rebuffed by de Gaulle. Indeed the changing British positions on the question of whether or not Europe should develop its own launcher — and after all it was the Macmillan government which in 1960 had proposed that it should — can be correlated with the ebb and flow of its hopes of gaining access to the EEC. Finally the Britain of the late-1960s was the Britain of Wilson's "white heat of technological revolution", and of an extremely powerful Ministry of Technology which believed that prestige and defence-related projects tended to squander public money, and that the procurement of advanced technological systems should be based above all on commercial criteria — and bought "off the shelf" from the USA if possible.

The second striking feature about these negotiations at Ministerial level is that, the deep divisions notwithstanding, there was *a persistent search for a* ***durable*** *compromise*. This compromise was not easily arrived at: it took time, eight years in fact, for the member states of ESRO and ELDO to "solve" the launcher problem, for example. Of course there was a good deal of raw horsetrading involved in finding "common ground", and it was facilitated by essential changes in the context in which the negotiations were conducted. The threats and the blackmail notwithstanding, concessions were made and bargains struck because all of those involved were determined not to fail.

Several factors account for this determination. The recognition, for the smaller European states, that if a collaborative effort involving the big four failed they would be more or less excluded from the industrial and commercial opportunities in the space sector. The awareness that collaboration in space was just one dimension of a general historic tendency towards European "unity", and that failure here would inevitably have repercussions in other sectors, scientific, technological, economic, and political. The need to have a European-based 'regional' telecommunications network, and a guaranteed market for the corresponding satellites. Finally, and perhaps above all, the realization that only by maintaining a united front could the Europeans hope to deal with the Americans from a position of some strength. This was true as concerns industrial policy in general, and space activities in particular.

The publication of Servan-Schreiber's "Le défi américain" in 1967 brought home to European governments the gap that had opened up between the continent and the United States in the field of advanced technology and provided the kind of competitive challenge that was needed to move them to action. A report published by the OECD in 1968 reinforced their determination. European firms were failing to compete with the United States, it argued, because their industrial structures were too small and because they could not manage the innovative process, particularly in high technology. It added that governments needed to transcend the national framework if they wished to redress this situation: research and development budgets and the scale of government procurement on the national level were simply insufficient to deal with the American threat. A cooperative space venture based on European consortia who competed for contracts respecting the principles of "just return" was the kind of mechanism which could, it was hoped, help to remedy the situation.

It was also believed that a jointly agreed policy was particularly important in the space sector. In the late 1960s and early 1970s the Europeans were negotiating arrangements with the Americans in two key areas. Firstly, there were the INTELSAT agreements which regulated global telecommunications traffic by satellite. The Europeans felt that they had been particularly disadvantaged vis-à-vis the Americans in the interim agreements reached in 1964. When the final agreements were negotiated in 1969 they wanted to secure the best possible terms for access to the market in a sector that was of immense commercial, political and cultural importance. Secondly, there was the American offer, made in 1969, that Europe participate in the post-Apollo programme. This programme, it was said, being based on a reusable launcher (the Shuttle) would revolutionize the cost of space operations, and would render conventional rocket technology obsolete. The Europeans were invited to share in several parts of post-Apollo bearing up to 10% of its costs (said to be some $1 billion in sum over ten years). Only by combining resources, and by agreeing on a joint approach to the US, could they hope to reap the technological and managerial benefits which participation might offer to their industries.

The *kind* of compromise deemed acceptable by the Ministers was one in which the different needs of the various parties had to be respected. There was to be no question of one or more countries, by virtue of their superior political or economic power, imposing their will on the others. The negotiations were, it was implicitly understood, to be conducted on a "level playing field". The French challenged this assumption once when, at the end of 1970, they threatened to withdraw from ESRO, and a broadly-based European space effort, if all their partners did not accept the need for an independent European launcher. They were immediately condemned by Britain, by Switzerland and by Sweden for seeking to negotiate from a "privileged" position. If the French persisted, they said, they too would threaten to withdraw — so re-establishing the balance of power, but also making any agreement impossible and effectively bringing the European space effort to a halt. The Dutch took a different line. In a remark thick with meaning they insisted that "unanimity cannot be commanded and participation cannot be compulsory." It was an affirmation of their conviction that a durable compromise could only be reached if a means was found to accommodate the wishes of even the smallest member states.

The compromises reflected the spirit in which the deals were struck. They were embodied in two package deals adopted in 1971 and 1973 and were based on what was known as the *à la carte* system. Member states were offered a range of programmes from which to choose, and they only had to participate in, and pay for, those which interested them. Percentage contributions were normally calculated on the basis of a country's Gross National Product. If the programme was particularly costly, however, its leading proponents (e.g. France in the case of a launcher, Germany in the case of collaboration in the post Apollo programme) took on the major financial burden, also retaining overall managerial and industrial responsibility. The only exception to the rule was the science programme, which was mandatory for all member states. These pragmatically inspired solutions might have disillusioned those who felt that opting out of some activities was contradictory to the ideal of European unity. But they were the sine qua non for the survival of the European space system in the early 1970s, and for its subsequent tenacity.

Bibliographic note: This paper draws on material in all the ESA-HSR reports published to date by the members of the ESA History Team.

Politicians, Experts and Industrialists in the Launch of ELDO: Some Pitfalls and How to Avoid Them

John Krige

Paper given at the conference "Technological Change"
Oxford, 8-11 September 1993

ELDO, the European Space Vehicle Launcher Development Organization, officially came into being in 1964. Initiated as an Anglo-French joint project, ELDO was eventually set up by seven states to provide Europe with its own heavy launcher capable of placing satellites in a low earth orbit. It lasted for less than a decade. After repeated efforts to upgrade its launcher, after an almost four-fold increase in its budget beyond the original estimates, and after one catastrophic failure of the rocket after the other, the member states finally decided to liquidate the organization in 1973. ELDO was one of the first, and certainly the most important, European scientific or technical organizations which has actually been shut down.

There have, needless to say, been many explanations put forward for ELDO's failure. The majority stress the technical and managerial structure of the programme. The rocket which ELDO aimed to build, and which was christened *Europa*, had three stages. The first was the British IRBM *Blue Streak*, stripped of its military characteristics and recycled for civilian purposes. The second stage was built by the French, using the experience gained in their national "Precious Stones" rocket programme. The third stage was built by Germany, who hoped to develop advanced cryogenic technologies for it. Finally the Italians were to provide a test satellite to be launched by *Europa*. The managerial structure reflected this quadripartite division of responsibility. Each national government retained control over its part of the rocket, including the placing of contracts with its industry. ELDO itself was left with very limited powers with respect to the technical and financial management of the project. This lack of centralized control and management led to the most absurd situations. For example, according to one eye-witness report, the different stages of the rocket were shipped separately from different countries to the launch pad in French Guyana in 1971. Each stage was accompanied by its own (national) team of engineers who had developed their own computer programmes to monitor the performance of "their" component. The rocket exploded in flight shortly after lift-off.

The striking thing about ELDO is that many experts believed from the start that the planned organization could never succeed, and strongly advised their governments against membership. Edoardo Amaldi, the doyen of postwar Italian physics and a founding father of CERN and of ESRO, was perhaps the most explicit of them. As early as December 1961 he put his finger on the difficulties which were later to beset the organization: cost, time-scale, complexity, the fact that the rocket would be obsolete when built (as measured by US developments), and the decentralization of the construction of the various stages. "Any responsible person," said Amaldi, "sees the difficulty of matching three stages and the satellite made in four different countries [...]." The decision to go ahead with ELDO, he went on, has "been taken at the highest political levels as a matter of bargaining and without any sound technical basis". Other sources tend to confirm this interpretation. A French "eyewitness" (Rhenter) has claimed that de Gaulle personally took the decision in January 1961 to associate his country with the UK in the joint development of a launcher based on *Blue Streak* "against the advice of all the experts." Similarly in February 1961, one of the most influential German rocketeers, Eugen Sänger, strongly advised his government against participation in the Anglo-French scheme. ELDO's collapse then seems to have been a foregone conclusion. As one of ESA's Director Generals (Erik Quistgaard) has put it, ELDO was "a child of non-technical parentage, of blindness to technical reality" in political circles. This "original sin" left an indelible and ultimately destructive stain on the organization.

This view, the view that ELDO was essentially a creature of politicians who played down or ignored technical and managerial difficulties, has been somewhat reinforced in recent work, notably by De Maria and Krige and just a few months ago by Krige alone. It is, of course, not entirely false. But at the same time it is, or can be extremely misleading. Indeed, new results by other researchers associated with the ESA history project, namely Lorenza Sebesta and Peter Fischer, and some rather underdeveloped arguments in the earlier papers, suggest that the idea that the launch of ELDO was politically "driven" — to use a current and very dangerous buzzword — is far too crude to capture the complexity of the case. My main aim in this paper is to show that neither the politicians nor, what is more to the point, the experts agreed on whether or not it was worth setting up ELDO along the lines proposed by Britain and France early in 1961. Both politicians *and* experts were divided among themselves over the wisdom of launching ELDO, and it is far to easy, with the wisdom of hindsight, to blame one party or the other, and politicians in particular, for the organization's alleged "failure". This is not to say that the technical and managerial structure with which ELDO was born was without its faults. But, as I shall suggest later, those "faults" are to be traced back, above all, to technical and political concerns which are usually not highlighted, factors which imposed their own, ultimately fatal, logic on the trajectory of the organization.

Before getting under way a quick comment about the notion that ELDO failed. This is true, but only in the limited sense that, during the lifetime of the organization, no rocket was built which put a satellite into orbit. That granted it is wrong to connect the dissolution of the organization solely with this technical failure. Indeed, ELDO was dissolved for three rather different reasons. Firstly, because the French, committed to acquiring an autonomous European launch capability, decided to take prime responsibility for building a launcher named *Ariane*. They had learnt from the ELDO experience how *not* to manage a large project, and could draw on the inhouse expertise that had been built up at their national centre (the CNES) under the framework of the *Europa* programme. Secondly, ELDO was sabotaged by a unilateral American decision not to build a space tug — a kind of interorbit shuttle — with Europe as part of its post-Apollo programme. The European side of this project had been allocated to ELDO, itself an act of confidence in the long-term viability of the organization, though perhaps in a new form. Related to this, it must not be forgotten that, under pressure from Britain to form a new single European space agency, ELDO was not actually "shut down" but merged with ESRO to form ESA. In short any judgement of ELDO's achievements which concentrates solely on the spectacular failure of the rockets it launched is far too one-sided. Let us continue to speak of failure if we must, but remember that we are using the word in a narrow, if crucial sense of the term.

Was ELDO "politically driven"?

If there is a case to be made for the claim that the foundation of ELDO was politically driven, then the forces at work in the UK would seem to be an ideal starting point. For it was the Macmillan government that were strong partisans of the scheme and who fought hard for its acceptance at home and abroad. A brief chronological account of the history of *Blue Streak* will help set the scene.

In the mid-1950s Britain, with American help, embarked on the development of an IRBM with a range of 1500 miles. The decision to do so was taken by the then Minister of

Defence, Duncan Sandys, who decided at the same time that the UK should develop an H-bomb as part of a general move to having an independent deterrent. By the end of the decade it was clear that the technology of the rocket, which was liquid fuelled, made it particularly vulnerable to enemy attack, so it was decided to house the missile in hardened underground silos. Costs soared. At the same time the strategic role of *Blue Streak* was taken over by the solid fuelled American *Thors* which were deployed on British soil in 1959. It was decided that what the UK needed was a mobile missile fleet. Arrangements were made to acquire from the USA the *Skybolt*, to be fired from the V-bombers, and the *Polaris* missiles, to be launched from submarines. In April 1960 it was announced to parliament that the *Blue Streak* military project would be cancelled after an expenditure of some £60 million on the rocket.

In parallel, and with the momentum growing for a scientific space research programme, the government thought to strip *Blue Streak* of its military characteristics and to recycle it as a civilian launcher. This would "save" the money that had already been spent, and would maintain an inhouse expertise at the RAE in Farnborough which would be available to develop the next generation of IRBMs should Britain later decide that she needed them. Above all, it could be used to demonstrate the UK's new goodwill towards European collaborative efforts. By offering *Blue Streak* as the first stage of a European heavy launcher, to be developed jointly with other major continental powers, Britain could, or at least so Macmillan hoped, "prove" that she would be a reliable European partner once admitted to the "club".

It fell to Macmillan's Minister of Aviation Peter Thorneycroft to "sell" the idea across the Channel. Thorneycroft made a tour of European capitals early in 1961 to sound out reactions. They were mixed. But with the help of direct and documented pressure from Macmillan first on de Gaulle, then on Adenauer and finally on Fanfani, the French, then the Germans and finally the Italians were persuaded to collaborate with the British. The deal that they struck has already been described: they would build together a three stage heavy satellite launcher based on *Blue Streak* as the first stage. The rocket would tested and fired from Woomera in Australia. To draw Belgium and the Netherlands into the scheme, they were offered the down range guidance station and the telemetry links, respectively. ELDO was thus born with seven member states, five of the six in the new EEC, plus the aspirant Britain, plus Australia.

This synoptic and admittedly selective account of the developments in the UK which led to laying the foundations of ELDO reinforces the claim that the organization was predominantly a political construction. Indeed we have no substantial evidence of pressure being brought on the government by independent "experts", including those at Farnborough, for the policies that were adopted. As for industrialists, businessmen in Britain and France certainly did undertake intensive lobbying in favour of the construction of a European launcher. However this was apparently not done in any systematic way until mid-1961 when high-level government officials in Britain, France and Germany had *already* decided to proceed with the project. It seems then we have a paradigm case of politics, and above all *not* of technology, as the "driver".

I want to insist that we must go beyond this beguilingly simple shorthand if we want to understand the messy process which led to the foundation of ELDO. It not only blinds us to the complexities of the political situation. It overlooks the fact that at least in *some* of the major countries *some* experts — and above all not the noisiest ones — were in fact in favour of the project.

The first point to stress about the political dimension of the launch of ELDO, a point obscured by talking about "drivers", is that there were marked differences of opinion within governments themselves about the advisability of the scheme, not to speak of vociferous opposition, at least in Britain, by the Labour party. So, for example, Macmillan was strongly advised by his science adviser, Sir Solly Zuckermann, not to turn *Blue Streak* into a satellite launcher, and Thorneycroft fought an ongoing battle against the Lord Hailsham, the Minister responsible for science, over the appropriate level of Britain's financial commitment to the joint scheme.

In similar vein, there were also initially major splits inside Adenauer's cabinet over the advisability of the scheme. Foreign Affairs Minister von Brentano and the Minister of Economics Erhard were both strongly in favour of collaboration. Both had a conception of European political and economic integration which included the United Kingdom, and both saw collaboration around *Blue Streak* as a way of binding the UK closer to the EEC. Against them were the Minister of Transport Seebohm, and the formidable Minister of Defence Franz Josef Strauß. Seebohm's motives were two. Firstly, his main adviser was the brilliant rocketeer Eugene Sänger. Sänger believed that conventional heavy launchers like that based on *Blue Streak* were primitive and uneconomical, and that the future lay in the development of a reusable shuttle. He and the Minister thus came out unequivocally against the scheme on "technical" grounds. Secondly, Seebohm knew that if this conception of space flight gained hold, his ministry would take over responsibility for one of the most important and costly new fields of technological development. His ambitions for himself and for his government department thus also shaped his assessment of the UK offer. Strauß's position was quite different. According to Fischer, for Strauß the establishment of a strong technico-industrial infrastructure was an essential dimension of power politics in the 1960s. The nuclear stalemate meant that direct armed conflict between the superpowers was unlikely. The technological Cold War had taken its place: it was at once the way to beat the Soviets and to strengthen Germany's position in the west. And the Minister of Defence thought that one of the best ways of doing this was to build advanced American weapons systems under licence. Suspicious of de Gaulle and so unwilling to commit himself to the French built *Mirage* fighter, in 1960 he concluded a deal to build 210 *Starfighters* (F-104's) in the Federal Republic. His initial opposition to the Anglo-French initiative for the joint development of a launcher followed a similar line of thinking. The technology was well established and the Americans were not directly involved. Far better, said Strauß, to build a technologically superior US rocket under licence. My point has, I hope, been made. There is no single homogeneous group to be labelled politicians who favoured (or opposed) the ELDO project. Leaving the experts out of the picture for the moment, politicians themselves were strongly divided over its suitability.

There is another related issue I should like to raise here, rather by way of an aside. Even when grouping historical actors into camps "for" and "against" a particular decision, it is important to remember that different individuals within in each camp can have very different motives for agreeing on what should be done. We have just seen this in the case of Seebohm and Strauß. Both initially opposed the Anglo-French proposal, but for very different reasons. An even more dramatic illustration of the point is provided by the attitudes of Macmillan and de Gaulle in favour of the venture. At a key tête-à-tête at the Chateau de Rambouillet in January 1961 the French President effectively threw his weight behind Macmillan's scheme to develop a European launcher. He did so because the French were keen to have access to British advanced technology for their "force de frappe". Collaboration in the development of a rocket, some parts of which had been built with American help, was a useful channel for gaining access to UK and, indirectly, US know-how for both civil and military purposes. By contrast, Macmillan's motives for seeking collaboration were not primarily technological but political. A few weeks before meeting de Gaulle in January 1961 the Premier decided that Britain should apply for membership of the Common Market, from which she had originally stood aloof, and which she had indeed tried to sabotage by setting up the alternative EFTA. For Macmillan technological collaboration was just one dimension of a wider strategy aimed at a closer integration with the Six, and an important "proof" of the UK's newly acquired European credentials. In short while both de Gaulle and Macmillan saw advantages in jointly sponsoring the construction of a European heavy launcher, they had very different motives for doing so. De Gaulle decoupled technological collaboration from European integration, Macmillan did not. It was a fundamental difference in perception, a difference which can help us understand Macmillan's controversial decision to apply for EEC membership in July 1961, and de Gaulle's veto of the request 18 months later.

The role of the experts

As we have stressed the argument that political considerations dominated the foundation of ELDO goes hand in glove with the view that the decision was not informed by technical considerations. More to the point it pits two social groups, politicians, conventionally seen as patriotic, selfserving bumblers incapable of thinking intelligently about scientific and technical matters, against experts, disinterested advisers who can see through rhetoric and can objectively assess the technical issues at stake in any policy choice. The case of ELDO certainly seems to substantiate this point of view. We have already cited Amaldi's prescient identification of the defects of the scheme, defects which he thought should be evident to any "responsible" person. We have heard the remark of a French eyewitness that de Gaulle went against the advice of all his experts — an opinion which derives some support from the fact that the French space science community immediately distanced themselves from the Anglo-French launcher project. Finally we have evidence of the same attitudes in Germany. As early as September 1960 the DFG (Deutsche Forschungsgemeinschaft) reported to the Federal government on the advisability of collaborating with the British in the recycling of *Blue Streak*. They declared themselves categorically against the scheme, for financial, political and psychological reasons. This was followed a few months later by the rocketeer Sänger's opposition to which we have already alluded. Surely then ELDO seems to have been a child of political (in the now richer meaning of the term we have explored), not technical parentage.

Again I want to insist that this way of putting the point is very misleading, not to say downright false. And that on two grounds. Firstly, it overlooks the fact that some experts *did* pronounce themselves in *favour* of the venture Secondly, it draws an entirely artificial distinction between political and technical concerns *in the advice given by experts*. The first point — that expert opinion was divided — emerges from new work done by Sebesta and Fischer on the Italian and German cases, respectively. According to one of Sebesta's sources, Amaldi's hostility to the scheme was not always shared by his colleague at the University of Rome, Luigi Broglio. Broglio was Italy's leading rocketeer and a champion of a strong national programme which included building the *San Marco* platform. Taking a more pragmatic line, in November 1961 he seems to have come round to the view that he could use membership in ELDO as an indirect means of stimulating a national programme. The test satellite atop Europa dovetailed neatly with his plans for building an Italian spacecraft. What is more Italy hoped, with the support of Germany, to push ELDO in the direction of doing research on advanced forms of propulsion, and indeed made this a condition of its membership. It was with this advice in hand that the government apparently took the plunge.

A parallel situation arose in Germany. First the DFG and then Sänger opposed ELDO membership. The government hesitated. However, in spring 1961 it set up a third expert group which contained, in addition, to academic space scientists, engineers, the directors of several big research institutes, financial experts, and representatives of the aviation and electronics industries. This group unanimously recommended that the German government participate in the construction of a European satellite launcher. A month later, and on the basis of this report, the Federal cabinet recommended that Germany join ELDO. In short, experts clearly made different assessments of the advisability of participation in ELDO. Even more important, at least in Germany and in Italy, the government only decided to join once they had these positive expert recommendations before them. Here at least we can (cautiously) turn the conventional slogan on its head: it was the experts not the politicians who were the "drivers"!

The *kind* of arguments used by the experts in Germany is also of interest. I cannot present them all. Suffice it to say that they involved a rich mix of technical, political, and industrial considerations. Certainly they saw German participation in ELDO as providing the opportunity to build a third stage which embodied advanced technologies. Above all, though, it was a way of jettisoning the historical burden of Peenemünde and the V2. The European project legitimated Germany's re-entry into space, it opened the way for German engineers and industry to take up R&D in the space sector once again, and it served as a booster for starting up a national space programme. Any sharp distinction between political and non-political considerations is without meaning here, of course.

One final comment. Implicit in what I have been saying is a quite different criticism of the politics/experts dichotomy as a pole around which to analyse the launch of ELDO. For this dichotomy overlooks the key role played by industry in the process. Our evidence is patchy here, but at least it is clear in the German case, where industrialists were actually members of the expert advisory group that recommended that the government participate in the venture. Soon thereafter, in the summer of 1961, all the leading European companies in aircraft and missile manufacture, and in electronics, grouped themselves together in a supranational body called Eurospace. Its explicit aim was to promote the development of aerospace activities in western Europe, including the space sector. These activities by industry — advising, organizing —, were welcome to governments who also saw ESRO and, above all, ELDO as instruments of national industrial policy, particularly in the high-technology sector. In short let us be careful not to get trapped in a "two cultures" model. There was a third and extremely important player in the launch of ELDO: the captains of industry.

An alternative explanation of why ELDO "failed"

Thus far my main aim in this paper has been to undermine a "standard view" about the birth of ELDO, the view that the undoubtedly cumbersome and inefficient technical and managerial structure of ELDO was put in place because politicians went ahead with the scheme despite the alarm sounded by scientific experts, and against their advice. I have argued that *both* politicians *and* experts were divided on the merits of the venture, and that those politicians and experts who favoured it, for a mix of scientific, technical, political and policy motives, were strongly encouraged by important sectors of the European aerospace and electronics industries. It follows therefore that we can no longer content ourselves with an analysis of ELDO's failure which is restricted to this level, to the arguments pro and con of these interest groups. Put differently one of my tactics in this paper has been to create the space needed for us to think again, and more deeply, about the particular features surrounding ELDO's birth for which it was to pay such a heavy price later.

The first that I want to stress is the very uneven level of development of rocket technology (and so also industrial and managerial experience) in the participating states and, related to this, the very different motives that their engineers, politicians and industrialists had for joining ELDO in the first place. Consider here simply the two extremes, Britain and Germany. *Blue Streak* had been under development by major British aerospace industries (Rolls Royce, de Havilland) since 1955/56, and was launched successfully on its own in June 1964, just a few months after the ELDO convention was signed. And it functioned correctly, not just once but in one test launch after the other. Development on the third German-built stage was of course far slower. In 1961 Germany had to start its space effort virtually from scratch, and its stage was first launched atop *Europa* in November 1968 — when it failed to function correctly. The point that I want to make is not that the German (and indeed French) stages arrived well after *Blue Streak*, or that they functioned less successfully, which was normal. It is that when ELDO was established those who framed its structure had to build an organization adapted to the fact that in the UK there was a rocket which was almost ready for launch while in Germany there was as yet no space activity to speak of.

The second important point to bear in mind about ELDO, and which sets its apart from ESRO, is the military/nationalistic dimension. In 1960/61 the conquest of space was the spearhead of the technological Cold War. Civilian and military aspects merged imperceptibly into each other, particularly in so far as the construction of rocketry was concerned. Indeed it was precisely for this reason that countries like Sweden and Switzerland refused to join ELDO though they did join ESRO — participation, they said, would jeopardize their neutral status. Perceived as being of military interest, it was only natural that governments would want to retain as much control as possible over their parts of the programme. ELDO was less a supranational organization than an instrument for the pursuit of national sovereignty — a goal which imposed strong constraints on the free exchange of strategically useful knowledge and experience.

In the light of these two considerations, it is hardly surprising that the ELDO secretariat was never given important financial and managerial authority, notably regarding the placing of contracts with industry. Typically, in organizations like ESRO and CERN governments paid their contributions into a central fund under the control of the Director General, and the management placed contracts with industry. In ELDO, by contrast it was agreed from the start that each government retained the authority to place contracts with its firms for its part of the programme. The most that ELDO did was to check the cost estimates coming from the national industries concerned. There were some pragmatic reasons for this, of course. The fact that the British component was so far advanced meant that it made no sense to pass control for the completion of the first stage to a central authority: all the administrative and financial aspects were already well in hand in the UK. The arrangement also allowed work to go on without hindrance before the convention was ratified, so accelerating Europe's entry into space — which after all was one of the arguments for using *Blue Streak* in the first place, rather than building a new all-European rocket from scratch. But above all, it meant that national authorities and industries could control the amount of information and expertise, technical and managerial, which they released to their "partners". Each member state could play the European card in trying to extract what it wanted from the other. Each member state could give away just as much it chose, and no more, by maintaining responsibility for its component. National industries could thereby protect their competitiveness in a sector that promised rich rewards from military and commercial contracts. But at the cost of transferring power to the ELDO executive and so at the cost of any centralized planning, control, or project management.

Concluding remarks

By way of conclusion I want to comment less on the "alternative" explanation which I have advanced for ELDO's "failure" than on the pervasiveness of the view that I have been criticizing. Why is it that the thesis that ELDO's difficulties can be traced back to the domination of political over technical considerations (and the blindness to expert advice) has been so prevalent? There are many reasons for this. It has been widely diffused by people personally involved in the European space effort. It fits neatly with certain a priori prejudices which many have about the social roles of politicians and experts. And there is substantial primary source material to support it. And it is precisely on this question of sources that I want to reflect for a few moments.

The prime source used for the study of the launch of ELDO has been government archives, and those in the UK in particular. This is justified by the fact that Britain was the prime mover in the founding of the organization and by the superb quality of the material in the Public Record Office. At the same time this approach imposes several constraints. Firstly, it is extremely difficult to study interdepartmental conflicts in any depth, simply because there is so much material. In the Foreign Office files for 1961 alone there are 960 folders dealing with ELDO and it would take months to go through them. Inevitably one has recourse to Cabinet papers, where the material is briefer, the conflicts submerged, and only the highest level of decision-making appears. Secondly, of course, official papers give mainly the UK view. Indeed it was precisely the research done by Fischer on Germany, where there is already a very active community working on the space effort, that threw so much light on the disputes between politicians. Thirdly official papers give a very selective impression of the views of experts and tell us very little about the role of industry. Let me elaborate.

The "experts" first. The expert advice which is most voluble and which leaves the greatest trace on the official record is that of eminent scientists. Indeed it striking how, at least in the postwar period, scientists have capitalised on their intelligence, prestige, and power to make their views known to both governments and the public alike. When thinking of "experts" one spontaneously tends to think of them — and the historian finds their pronouncements everywhere, including of course in the government archives. Yet they were far from disinterested in this case. They feared that ELDO would be built at the expense of their research budget, and they knew that they could launch their research satellites with US rockets if they wanted to. Many, perhaps even all the experts were against ELDO — all the space scientists that is. Some influential engineers by contrast were not. And if we have not given them sufficient weight before it is because they are quieter, less prestigious, and often based in industry where to make one's views public is frowned on. They simply have different links with government and so we do not find them in our "official" sources.

This brings me to the third great gap in the model that I have been criticizing: the role and the lobbying of industry. Not only has very little been done on this, at least in Europe. It is also very difficult to do. Most big firms either do not have archives, or are loath to open them to scholars. This is the case with Eurospace for example, who is apparently writing its history, but only for internal consumption! Furthermore the captains of industry apply their pressure on politicians discreetly, by personal contact rather than by formal meetings and letters. Documentation on industrialists is thus sparse, it is difficult for the historian to reconstruct their activity, and they all too easily fall out of the historical picture.

There are three little lessons to be learnt from this. Firstly, we need to build up a critical mass of scholars working towards shared objectives in different European countries, knowing the language and the sources in their own country. Secondly, we must study engineers more carefully: they are certainly at least as important if not more so than the far better known scientists, at least for any technologically based project. Thirdly, we need to write good business histories of the major European firms involved in advanced technology. Only when these gaps are filled can we hope to grasp in all their richness the complex processes which have led to the choice of big technologies in postwar Europe.

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The Early Development of the Telecommunications Satellite Programme in the European Space Research Organization (ESRO) [1]

Arturo Russo

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On June 28th, 1965, the American satellite *Early Bird* inaugurated a commercial satellite communications service between Europe and the United States. After several years of experimentation with satellites like *Echo, Telstar* and *Syncom,* this less-than-40 kg spacecraft orbiting 36,000 km above the Atlantic ocean demonstrated the technical feasibility and economic importance of geostationary communications satellites and marked the beginning of a new era in the history of telecommunications. *Early Bird,* eventually renamed *Intelsat I,* was followed in 1967 by three *Intelsat II* satellites. Two years later, the third generation of Intelsat satellites established a world-wide service, with one satellite over each of the earth's oceans and many ground stations spread all over the world.

All important developments on satellite telecommunications in the 1960s occurred in the United States, and the U.S. dominated the international consortium Intelsat, created in 1964 with the task of establishing and operating a global commercial system. By this time the European countries had undertaken a cooperative effort in this field, with the twofold aim of qualifying the European industry in the competition for Intelsat procurement contracts and of realizing a communications satellite system suitable for the European continent and the area of its cultural influence in North Africa and the Near East. In May 1963 the European Conference for Satellite Telecommunications was established (CETS from its French initials), and by the end of 1964 the first plans were elaborated to develop a viable research and development programme.

Four main difficulties presented themselves regarding the achievement of an independent European capability in satellite telecommunications. The first was that two multinational space organizations had already been created in Europe, one to build scientific satellites (ESRO) and another to develop launchers (ELDO), but none existed for building and operating applications satellites. While the creation of a third organization appeared unwise, any eventual involvement

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[1] This paper is based on the author's ongoing research on ESRO's and ESA's telecommunications programme, in the framework of the ESA History Project. For more detailed analysis and for source references see A. Russo, *The early development of the telecommunications satellite programme in ESRO (1965-1971),* ESA HSR-9 (Noordwijk: ESA, May 1993).

of those existing in the new field implied changing their charter and operational programmes. This was not easy, however, due to the different aims, structure and membership of these organizations. Only six European countries, plus Australia, were members of ELDO, whose programmes were mainly defined at governmental level; ten were in ESRO, whose constituency was the European space science community; and nineteen participated in the CETS, most of them represented by their post and telegraph administrations (PTT).

The second difficulty was in the lukewarm attitude of many European PTTs towards a communications satellite system outside the Intelsat framework. While the latter was improving communications across the oceans with the important support of American technical know-how, satellite links within the European continent appeared uneconomical compared with the rapidly expanding ground network, and the PTTs were reluctant to embark on such a new technology. Thirdly, Europe lacked a launcher capable of putting a satellite into the geostationary orbit. The rocket under development in ELDO was not qualified for this and therefore any independent European programme implied either the use of American rockets, and it was not evident that this would be granted when commercial interests were at stake, or an important change in ELDO's programme. Finally, the European countries not only were committing themselves to the realization a joint space telecommunications programme but they also wanted to pursue their own national political interests and develop their national industry in the framework of a comprehensive space policy at continental level. This often implied antagonism and conflict whose solution was a *sine qua non* condition for any significant result to be achieved.

The definition of a suitable institutional framework, the emergence of an important and reliable customer, the building of a launcher with geostationary capability, and the definition of a European space policy acceptable to all interested parties were thus necessary preconditions for the successful implementation of a European communications satellite programme. This was a long and painstaking process, lasting almost ten years, which was intertwined with the laborious negotiations which ultimately led in 1975 to the birth of the European Space Agency.

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The start of a viable European communications satellite programme required the definition of the respective roles of ESRO and ELDO.

ESRO, the European Space Research Organization, had been formally established in 1964, after three years of negotiations, as an organization solely devoted to space research. Its programme included the launching of sounding rockets and spacecraft to investigate physical phenomena in the upper atmosphere and the earth's space environment, and to observe celestial bodies from outside the atmosphere. While scientists were worried about the eventual engagement of the Organization in application programmes, the ESRO executive and technical staff looked upon these prospects with enthusiasm. A balanced programme involving scientific and application satellites involved in fact a more efficient use of capital resources, a more equitable distribution of industrial contracts among member states, and the recruitment of the best engineers by the appeal of large challenging projects. In the event, ESRO was entrusted by the CETS with the task of managing the telecommunications programme and designing the satellites.

As to ELDO, the European Launcher Development Organization, it was also established in 1964 at the end of a long decisional process, with the aim of developing a three-stage rocket, called *Europa*, capable of launching large satellites into near earth orbits. Subsequently, after the demonstration of *Early Bird*, ELDO member states decided in July 1966 to undertake a new launcher project, called *Europa 2*, consisting of a modification of the *Europa* vehicle in order to make it capable of injecting a small satellite into geostationary orbit. ELDO, however, was hampered by severe managerial problems and the cost of the programmes escalated dramatically. In this situation a strong disagreement arose between countries sceptical about the prospects of a European launcher development programme and those firmly committed to achieving European autonomy in launching capability. Britain and France led the opposite camps, the former stressing the high cost of the envisaged European launcher in comparison with American rockets, and the latter insisting that Europe could not sustain a credible space policy without the availability of its own launchers. For several years the disagreement about launchers was the main obstacle to the development of a joint space programme in Europe and risked in fact making the most generous efforts vain.

Following the decision to undertake ELDO's *Europa 2* programme, the CETS asked ESRO to design a joint European programme for the development of experimental satellites for telephony and television distribution comparable to the *Intelsat III* satellite then under development. This programme was worked out in the first half of 1967 and presented at the meeting of the European Space Conference (ESC) held in Rome in July that year. The conference had been convened to discuss a coherent European space policy but indeed, in that summer of 1967, the prospects for such a policy could hardly be considered with optimism. ESRO was living a dramatic institutional and financial crisis because of strong disagreements between its member states about the industrial return of its programmes. The Organization's most important project, a Large Astronomical Satellite (LAS) for high resolution studies of stars in the ultraviolet, seemed definitely jeopardized and a drastic reduction of its initial programme was inevitable. With regards to ELDO, the approval of the *Europa 2* programme had not removed the reasons for conflicts between member states. Foreseeable developments in satellite telecommunications and other application fields called for much heavier satellites and more powerful rockets, but Britain still had serious doubts about the viability of *Europa 2* and was adamantly against undertaking new projects. Finally, regarding the telecommunications programme itself, the technical optimism of ESRO engineers contrasted with the uncertainty about the economic aspects. The organization of the European PTTs (CEPT) had calculated in fact that a communications satellite system for Europe would be more expensive than the conventional ground links. As a consequence, the distance between the major European countries sharpened dramatically. The British Post Office opposed any direct involvement in communications satellites, as they thought that very few possibilities existed for autonomous European action in this field, both because of the strength of the American presence and because of the foreseeable small commercial demand for the kind of satellites Europe could build and operate. European countries, the British argued, should concentrate all efforts on obtaining more favourable conditions for their industrial interests within the Intelsat framework. France and Germany, annoyed by the dragging on of pan-European ventures, announced that they would develop a joint project, named *Symphonie*, whose mission was very similar to that of the ESRO/CETS project. Eventually, Italy too decided to start a national programme called *Sirio*, and Britain joined the Americans in a project for a military communications system called *Skynet*.

Unable to find an agreement, the Rome Conference set up an Advisory Committee on Programmes, chaired by J.-P. Causse, with the task of elaborating a coherent space programme for Europe. At the same time, ESRO was granted a new contract to design a satellite distinct from *Symphonie* and meeting the needs of the European Broadcasting Union (EBU), the association of television companies which operated Eurovision. The EBU had a strong interest in communications satellites. The transmission of Eurovision programmes, in fact, was realized through a network provided by the PTTs on a commercial basis. But the activation of such a network required several hours; the cost of the service was considered too high; and the distribution was limited to the countries connected to such a network. The availability of a satellite relay system could provide the EBU with its own distribution network, which could be operated in real time at short notice, and capable of reaching all countries from which the satellite was visible, from Iceland to Lebanon and from Scandinavia to North Africa.

Pending the decisions of the European Space Conference, the opportunity provided by the EBU presented several advantages. Firstly, it allowed ESRO to keep its technical team united instead of dispersing it. Secondly, it offered the CETS a way out of the embarrassing situation of having a "European" project similar to that developed by two of the most important European countries. Finally, it provided the example of a communications satellite more oriented towards operational activity for a definite customer than towards experimentation.

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By the end of 1967 ESRO's engineers presented the new project, called *Eurafrica*, meeting the requirement of the EBU. The latter reaffirmed its interest and specified that they were ready to bear the cost of the operational satellites following the experimental one, provided that the annual average expenditure of the system did not exceed that of the terrestrial network. The Causse Committee was also much interested in *Eurafrica* and recommended that the project should be initiated in the first phase of the "balanced space programme" proposed in its report. The second phase of the programme foresaw the development of second generation communications satellites and of a launcher with greater capability than *Europa 2*. Then, in the longer period, it was proposed to continue with more powerful rockets and more ambitious scientific and application satellite projects.

The implementation of the programme discussed in the Causse Report required a political decision which was expected from the forthcoming meeting of the European Space Conference in Spring 1968. But in April a political bombshell exploded when the British government announced that the United Kingdom would not undertake further financial commitments to ELDO and would not participate in the Eurovision satellite project. In this disarray there was no foundation for convening the Conference and it was hard not to despair of a European future in space. And just to make things worse, in December the first test flight of the *Europa 1* rocket with all three stages operational was a failure, the last of several previous unsuccessful tests.

After several months of intense negotiations a tentative compromise was worked out and the European Space Conference could finally be called in November 1968 in Bad Godesberg. The compromise was based on two main elements. Firstly, that one European space organization should be created out of the existing ESRO, ELDO and CETS, with a minimum programme (still to be defined) mandatory for all member states and a number of optional programmes in which only the interested states would participate. Secondly, that the programme for a European rocket could be pursued further by interested states but, in order to protect the interests of non-launcher states, the latter should not pay for an ELDO launcher any price difference higher than 25 per cent of the price of a comparable non-European vehicle.

Following the Bad Godesberg compromise, a Committee of Senior Officials was set up by the ESC to establish the framework of the envisaged new European space organization, while Belgium, France, Germany and the Netherlands agreed to make up for the reduction of the British and Italian contributions to ELDO and decided to start studies on a new rocket, called *Europa 3*, capable of launching geostationary satellites with a mass up to 800 kg, the size of the communications satellites foreseen in the late 1970s.

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While negotiations were going on, the Eurovision satellite project did not progress much and ESRO was only authorized to continue its preliminary studies and to start an industrial consultation for the design of the *Eurafrica* satellite. But in November 1969 the project was definitely jeopardized when a new evaluation of the EBU showed that a television relay satellite system would be more expensive than the terrestrial Eurovision network it sought to replace. A new possible client appeared at the same time, however. The CEPT in fact announced that they wished to explore the feasibility of a communications satellite system capable of providing allowance for intra-European telephony, telex, and data transmission, besides the TV relay demanded by Eurovision. A working group of all interested parties was set up by the ESC Committee of Senior Officials and a new programme designed, whose objective was to provide in the 1980s a satellite system capable of handling a significant fraction (say one half) of the total telecommunications traffic between CEPT member states, and distributing two Eurovision programmes. One or two large (700 to 800 kg) satellites were assumed as the basic element of the system, which would also include 30 to 35 stations in Europe, North Africa and the Near East. The cost of the programme was estimated at $ 450 million.

The reasons for CEPT's new interest in communications satellites can be easily recognized. In July that year the *Intelsat III* satellites started providing world coverage for telephonic traffic and enabled some 500 million people to watch the television pictures of the first landing on the moon. The technical reliability, commercial value and social importance of communications satellites could not be doubted any longer. Moreover, in the framework of the ongoing negotiations for the definitive Intelsat agreements, it had been finally accepted in principle that regional (i.e. at sub-continental level) systems of communications satellites could be established besides Intelsat's global network. With the coming of the PTTs, the ESRO executive felt confident that a reliable partner had finally been found and a politically appropriate framework created: the post and telegraph administrations not only held legal monopolies on telecommunications but were also part of the governments which were to be involved in the programme. For three years ESRO had been, in the words of its director general Hermann Bondi, "like an athlete 'limbering up' in anticipation of the starter's gun, at the same time being somewhat uncertain when the gun would, in fact, be fired". Now it was reasonable to expect that governments would finally give the eagerly awaited full approval of the communications satellite programme.

Bondi's optimism was not justified, however. Two sessions of the fourth meeting of the European Space Conference, in July and November 1970 in Brussels, did not succeed in reaching an agreement on the critical issue of launchers, and all plans for a unified European space organization receded dramatically.

The question whether Europe should build its own vehicle or rely on American launchers was tightly intertwined with the very feasibility of an all-European communications satellite system. NASA in fact had always been willing to provide launching facilities for European scientific satellites but its position was ambiguous regarding application satellites, and it appeared that the U.S. would be unlikely to launch communications satellites possibly competing with the Intelsat system. For Britain the situation was plain: the Americans should be trusted and the ELDO experience had shown that it made no sense to embark on uncertain and expensive programmes to achieve European independence. This argument was made stronger by the consideration that the NASA post-Apollo programme included the development of a re-usable space shuttle whose advent, it was claimed, would deeply modify the technology and economy of all space activities. For France, on the contrary, independence was a political need which dwarfed all economic considerations. Unlike the British, they were sceptical about the American willingness to launch European application satellites, and insisted that a space policy without launching capability would be meaningless. Germany, finally, was much interested in the NASA offer to participate in post-Apollo programmes, and made it clear that this was definitely more important for her than continuing in the *Europa 3* programme. With France, Britain and Germany providing about three-quarters of the total ESRO and ELDO budget a deadlock was inevitable. No real progress could be made without finding a compromise, a "package deal" as it was eventually called, satisfying these three countries' interests.

An important step was reached in December 1971, when ESRO member states agreed on a first "package deal". This essentially consisted in the decision to implement within ESRO the optional programme system designed at Bad Godesberg for the envisaged space agency. ESRO was thus transformed from an organization solely devoted to space research into one mainly involved in application programmes, with only a minor fraction of its budget devoted to science. Only the scientific programme was made mandatory for member states, while all application programmes were optional. On this basis, and leaving aside the controversial question of launchers, the start of the telecommunications programme was finally approved by eight of ESRO's ten member states (Belgium, Denmark, France, Germany, Italy, Sweden, Switzerland and the United Kingdom) and a budget of $ 100 million was granted to ESRO for the execution of its first phase.

A few weeks before this important event, on November 5, the first — and actually the last — launch of the *Europa 2* rocket ended in a dramatic failure and this tolled the knell for ELDO. Eventually, the *Europa* programme was cancelled and a new package deal worked out and approved by the European Space Conference in July 1973. It envisaged the creation of a European Space Agency essentially centred around ESRO, whose activity would include science, applications and launchers. All programmes of the new agency except for science were to be "*à la carte*", namely each country decided to join with a percentage contribution of its own choice. The leading member states thus had their own favourite programmes approved but committed themselves to provide most of the money required for their actual implementation. France contributed 63 per cent to a new launcher development programme based on a French design and eventually called *Ariane*; Germany covered 54 per cent of the Spacelab project within the framework of the NASA Space Shuttle programme; and Britain covered 56 per cent of a new application programme for a maritime satellite (MAROTS).

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While policy-makers were negotiating a way out of the mess of the European space policy, the telecommunications programme was also suffering from problems and difficulties. As we have seen, the outline programme designed in 1970 to fulfil the requirements of the CEPT and the EBU survived the dramatic crisis of the European Space Conference and was one of the main elements of the ESRO package deal of December 1971. This programme foresaw the development of advanced spacecraft and communications technologies, in order to leapfrog the technological gap accumulated in Europe *vis-à-vis* the United States. Three axis stabilization, sun-tracking solar array, carrier frequencies above 10 GHz, spot-beam antennae, frequency re-use, etc., were among the most distinctive aspects of the design, which implied an important R&D effort both in ESRO and industry. As a consequence, a two-phase programme was defined, the first to be devoted to developing the required advanced technology and testing critical equipment on board an experimental satellite, and the second to the development of the operational satellite meeting the users' requirements.

Two problem areas presented themselves in the early phase of programme development. The first regarded the economic aspects of the envisaged European communications satellite system. According to a study prepared by the CEPT, the total investments required to operate such a system in the 1980s (i.e. not considering the R&D costs and the building and launch of the first satellite) would be much in excess of the savings in the terrestrial network achievable as a consequence of the transfer to the satellite system of part of the telecommunications traffic. And the CEPT made it clear that the effort of supporting the European space industry could not be paid by the customers. Besides financing R&D activities through ESRO, governments had to make themselves responsible for the difference between the actual operating costs of the satellite system and those which the PTTs would normally have to bear. As a solution to this problem it was agreed that the two phases of the programme should be broken down into two different programmes, each requiring special approval: the first aiming at developing and launching the experimental satellite; the second at developing and launching the operational satellite. While the decision to undertake the experimental programme was taken in 1971, contextually with the approval of the first package deal, a decision about the operational one was required only in 1975, thus leaving enough time for clarifying the economic aspects and obtaining the commitment of potential users.

The second problem area regarded the relationship between the ESRO programme and the ongoing national programmes, in particular the Franco-German *Symphonie*. France and Germany, supported by Italy, argued that ESRO should take advantage of the technology and expertise available as a consequence of national efforts, and insisted that the experimental satellite should be essentially based on the *Symphonie* (or *Sirio*) design. On the contrary, the countries without a national programme in communications satellites opposed any national bias in the joint European programme, and advocated a new design for the experimental satellite. Good technical reasons existed for both arguments but the real issue, of course, was not technical: at the start of an R&D programme with such important economic implications, all countries wanted to guarantee their home industry the most favourable conditions.

By mid-1972 this controversy brought ESRO to a deadlock, with France and Germany insisting on the proposal of their *Symphonie*, Italy advocating the use of a modified version of *Sirio*, and even Britain announcing its intention to develop a national communications satellite also usable in the European programme. In a situation in which the main member states blocked each other, the ESRO executive decided to play European. By-passing the national delegations, it contracted with industry a design for a dedicated experimental satellite whose configuration should be as close as possible to that of the operational one that industry itself was then starting to study. This project, named OTS (Orbiting Test Satellite), was whole-heartedly supported by ESRO's smaller member states and, in the event, approved by the Council. In September 1973 the participating countries agreed on the new financial plan and in November the construction of the OTS was finally contracted with industry.

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We will not discuss here the subsequent development of ESRO's and then ESA's communications satellite programme. Let us just recall that the OTS satellite was put in orbit by an American *Thor Delta* rocket in May 1978. Earlier that year the second (operational) phase of the programme had been approved and the first fully operational satellite, called ECS (European Communications Satellite), was eventually launched in June 1983 by *Ariane*. We can conclude with some considerations about the political dimension of the difficult start of satellite telecommunications in Europe that we have discussed in this paper. From the technical point of view, designing and developing a communications satellite system was an interesting and stimulating job for ESRO's engineers and an important opportunity for the European industry. The challenge was accepted and good results eventually obtained. The economics of such a system was quite a different matter, however. The lack of enthusiasm among PTTs derived not only from a generally conservative attitude but also from the great uncertainty about the actual viability of intra-European satellite telecommunications. In the event, it was politics that provided the necessary impulse. The decision not to rely on the Intelsat system within the area of European cultural influence, the decision not to be dependent on American launchers, and the decision to qualify the European industry for prime contractorship in the market of communications satellites, were all aspects of a wider political initiative which involved foreign policy, scientific and industrial policy, and economic and commercial interests.

In this framework we can see a kind of swinging pendulum between European cooperation and national interests. Facing American initiatives in the early 1960s, European countries created the CETS and tried to make the best use of ESRO and ELDO. But the conflict between different interests and concerns made discussions frustrating and decisions useless. Limiting ourselves to consider only the main European countries, France regarded space as a key element in President de Gaulle's policy of military and technological independence from the United States; Britain as a business to be pursued as long as it produced an economic return; Germany as an important element for the country's technological development, particularly in the fields where its industry was highly competent, like communications electronics; and Italy as an opportunity for its national industry. With the crisis of ELDO and the success of Intelsat satellites, in 1967-1970, the pendulum swung towards national or bi-national projects (*Symphonie*, *Sirio*, *Skynet*). But *Symphonie* needed a launcher, and France and Germany needed British support to build it. The pendulum had to stay in the "European" field, where the ESRO directorate and ESRO's smaller member states (Belgium in particular) could play their best cards. Politics demanded that both European ventures and national programmes be protected. A package had had to be reached for Europe to keep a decent role in space, and ESRO's technical and managerial success provided a good basis for it. The dreams of a joint European undertaking in space thus came true in the only form actually possible, namely as an agreement that under the flag of a European agency warranted the fulfilment of different national interests.

Big Science in Space: The Case of the Giotto Mission of the European Space Agency [1]

Arturo Russo

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The term "big science" is commonly used by historians and sociologists of science with reference to experimental research in the field of elementary particle physics. It refers to the bigness of the technical hardware required, i.e. huge accelerators and detectors; to the large dimension of the institutions where this kind of research is pursued (e.g. CERN, Stanford or Fermilab); to the importance of the budgets required for running such laboratories and building the necessary apparatus; to the political dimension of scientific and technical choices; and to the complex managerial activities required for conducting experimental programmes which often involve hundreds of scientists from many different institutions. In recent years, the term "big science" has also been introduced for space research. Also in this field, in fact, the size of technical hardware, the dimension of institutions involved, the magnitude of budgets, the importance of politics and the sophistication of management are such that this definition seems justified. And of course it is not just a matter of definitions: for historians this means that in order to fully understand the historical development of space research, one has to consider with great attention those political, economic and social aspects which are inextricably interlaced with the cultural dimension of post-war science.[2]

Several differences exist between particle physics and space science, however, and I wish to point out two of them which seem to me the most relevant. Firstly, unlike particle physics, which refers to a well-defined research field and a homogeneous scientific community, space science

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1 This paper is mainly based on interviews with the following protagonists of the Giotto mission: R. Bonnet, J. Credland, D. Dale, A. Johnstone, H.U. Keller, J. Kissel, D. Krankowsky, A.-C. Levasseur-Regourd, J.A. McDonnell, F. Neubauer, R. Reinhardt, H. Rème. These interviews were realized in the framework of the ESA History Project and of the American Institute of Physics project on multi-institutional collaborations in space research. The author wishes to thank J. Warnow and J. Genuth, from the AIP Center for History of Physics, for making available to him the transcripts of their interviews. Of course, the conclusions contained herein are solely the responsibility of the author.

2 A useful introduction to the problematics of big science and to the relevant bibliography is offered by J.H. Capshew & K.A. Rader, "Big science: price to the present", in A. Thackray (ed.), *Science after '40*: *Osiris*, vol. 7 (1992), pp. 3-25. Interesting case studies are discussed in P. Galison & B. Hevly (eds), *Big Science*, Stanford, Ca.: Stanford University Press, 1992.

covers a broad collection of disciplines and involves a large variety of scientific objectives and methodological approaches. Secondly, while particle physics stands with its own cultural and methodological autonomy in the general field of science, space research is deeply embedded in a non-scientific context: it owes its very existence and development to the use of technologies (rockets, spacecraft and communication techniques) whose primary implications are in commercial and military applications. We should not compare rockets, spacecraft and ground stations to the accelerators which fuel particle physics experiments or the large detectors associated with them. The latter in fact are an intrinsic and stable element of this research field; designed according to scientists' requirements and performing (in terms of kind and energy of particles produced, events recorded, etc.) according to the needs of specific experimental programmes. The former, on the contrary, only constitute technical devices which provide scientists with the possibility of placing their instruments in a certain position in space and getting data from them. The technical characteristics of such devices and their cost determine the size and characteristics of possible experiments.

In this paper I wish to present the European Space Agency's Giotto mission with the aim of discussing the sense of the term "big science" when used for space research. While remarkable for its achievements and its impact on the public's imagination, the Giotto mission can in fact be considered a typical exemplar of scientific research in space. It involved the use of a medium-size spacecraft, launched into outer space by a medium-size rocket, and carrying a number of scientific instruments designed to study physical phenomena involving a celestial body and its space environment. So the question I would discuss here is: "Should Giotto be regarded as big science?" Or a better question to ask might be: "How big was Giotto?" And I shall give an answer by considering the following set of parameters: size, money, policy, geography, time scale, people and management.

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The aim of the Giotto mission was to bring a spacecraft to a close encounter with the Halley comet during its passage near the earth in the winter of 1985-1986. The scientific objectives for the mission were to identify and provide images of the cometary nucleus, and to investigate the physical properties of the cometary matter and its interaction with the solar radiation. The mission acquired its name because it is believed that the first realistic portrait of this famous comet is in the beautiful cycle of frescoes painted by Giotto di Bondone at the beginning of the 14th century, in the Chapel of the Scrovegni family in Padua. Giotto in fact could not fail to observe the comet during its appearance in September 1301, and he represented it with great realism as the star of Bethlehem in the painting of the Adoration of the Magi.[3]

Giotto was not alone in its journey to Halley. In fact it was one of a fleet of five spacecraft that also included two launched by the Soviet Union, called Vega-1 and -2, and two launched by the Japanese space agency, called *Sakigake* (i.e. "Forerunner") and *Suisei* (i.e. "Comet"). All the encounters of these spacecraft with Halley occurred within a week of each other, between 6 and 14 March 1986, Vega-1 being the first and Giotto the last. The characteristics of the encounters were very different, however. Vega-1 and -2 were very large spacecraft carrying several instruments for remote sensing and in-situ measurements, and passed the comet at a distance of about 9000 km and 8000 km from the nucleus, respectively. Suisei's main instrument was an ultraviolet telescope to observe the comet from a minimum distance of 151,000 km; and the other Japanese spacecraft, Sakigake, carried instruments designed to observe the solar wind and plasma waves at a distance of 7 million km from the comet. Giotto, finally, was to act as a sort of kamikaze, approaching the comet at less than 600 km in order to get a close-up view of the nucleus and its atmosphere. Passing at a speed of about 70 km per second through the thick cloud of dust and gas surrounding the cometary nucleus, there was very little chance of survival for the spacecraft and its scientific instruments. The Giotto mission, which had required two years for decision-making, five years for building and launching, and eight months of cruising in space, was to collect its relevant data only in the very last hour of its lifetime.[4]

Looking at its size, Giotto was more or less comparable with similar space science missions. Shaped as a cylinder 1.8 m in diameter and 1.5 m high, plus a 1.3 m high tripod holding an antenna, the spacecraft weighed 958 kg at launch. While being the heaviest scientific spacecraft launched by ESA until then, its weight can be compared with the 815 kg of the two NASA *Voyager* spacecraft that had provided pictures of Jupiter and Saturn between 1979 and 1981. Giotto, however, was much smaller than the 4.5 ton Vega spacecraft (which also included a 2-ton module to be shed into the atmosphere of the planet Venus), and much bigger than both Japanese spacecraft, weighing no more than 140 kg. When discussing the physical dimension of a space science project, however, we should consider that the scientific experiments themselves usually take only a very small fraction of the total mass involved (Table 1). Of Giotto's 958 kg, in fact, only 59 kg (i.e. 6 %) were taken by the ten scientific instruments which made up Giotto's science,

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[3] A popular account of the Giotto mission is offered by N. Calder, *Giotto to the Comets*, London: Presswork 1992. See also *Giotto Special Issue*: *ESA Bulletin*, n. 46, May 1986.

[4] As a matter of fact, the spacecraft and most instruments survived the encounter with Halley and it was then decided to extend the mission and to direct Giotto to an encounter with Comet Grigg-Skjellerup. This encounter took place on 10 July 1992, when the spacecraft passed within approximately 200 km of the cometary nucleus, 214 million km from the earth. See G.H. Schwehm, "Giotto's encounter with Comet Grigg-Skjellerup: the first results", *ESA Bulletin*, n. 71 (August 1992), 10-13.

i.e. detectors and associated electronics. (The heaviest instrument was the multicolour camera, weighing 13.5 kg; the lightest was the energetic particle analyser whose weight was less than 1 kg.) The rest was shared by the spacecraft structure and sub-systems, the on-board motor, and the propellant, the latter in particular constituting 46 % of Giotto's total mass. And the importance of Giotto's scientific apparatus from the point of view of physical dimensions is still less relevant if we consider that a 200 ton, 47 m *Ariane* rocket was required to send these 59 kg of instruments to visit Halley, and antenna dishes as large as 64 m were used to follow Giotto's journey in space and receive its data. In conclusion, from the point of view of physical dimensions, what is big in space science is the structural support that make experiments possible rather than the size of the experimental apparatus itself. A space science mission is much more a matter of engineers than of scientists.

The total cost of the Giotto mission for ESA was estimated at about $ 200 million. This is certainly a large amount of money but the figure must be qualified by two important considerations. The first is that it includes the cost of the spacecraft, the launcher, the tracking and telemetry link, the data reduction and the project management; it does not include the cost of the scientific instruments, which were provided by scientific institutions outside the Agency and paid for by national funds. The total cost of these instruments was estimated at about $ 40-50 million. Giotto's scientific payload included 10 different experiments, provided by about 30 laboratories in 7 European countries and the United States. Big differences existed between them, both from the point of view of technical sophistication and regarding their cost. But we can reasonably conclude that the financial burden for the institutions that funded these experiments, while being sometimes considerable, can hardly be defined "big". And in fact, once having their experiments selected for the Giotto mission, it was not difficult for the scientists involved to obtain the money necessary to build them from national funding agencies. The second consideration regards the place of science in the general framework of space activities. The European Space Agency, in fact, is not devoted solely to space research as CERN, for example, is institutionally devoted to particle physics. On the contrary, space science is only a small fraction of ESA's activities, covering about 10 per cent of its budget. In other words, from the point of view of the ESA budget, Giotto could be considered a kind of by-product of a complex of activities which required, in the period when the project was being implemented, the spending of about $ 1 billion per year. From the point of view of budgets, we see again that what is big in space research is not science but its institutional context.

The selection of Giotto as an ESA mission was an important political decision that involved most of the European space science community. Politics in fact was called for both because Giotto was a key element in the definition of the Agency's scientific policy, and because of problems arising from the multi-national constitution of ESA. A flyby mission to the Halley comet was originally designed as ESA's minor contribution to an ambitious cometary mission planned by NASA. This mission foresaw the launch of a spacecraft using solar-electric propulsion and targeted to a rendezvous with comet Tempel-2 during its 1988 apparition. A passive probe provided by ESA would be released from the main spacecraft to meet Halley at the end of 1985. In January 1980, however, the NASA project was cancelled and the European scientists already involved in it suggested that ESA adopted the Halley mission in its own programme. Thanks to the lobbying of this group of scientists and to the generous support of ESA's Director of Science, Ernst Trendelenburg, the proposal passed quickly the complex decision-making procedure of ESA's advisory committees and was approved in July, in time for implementing the project before the last useful launch date in the summer of 1985. Giotto thus became the first European spacecraft to fly out of the earth orbit and the first ESA mission devoted to planetary science after a long dominance of high energy astrophysics and magnetospheric physics. The inclusion of the cometary mission in the ESA programme implied the delay of the astrometry satellite *Hipparcos*, already approved in the programme and strongly supported by the French scientific community. The French delegation in the ESA Science Programme Board, in fact, voted against Giotto, which appeared to them a predominantly German project.

Political considerations were also involved in the selection of the scientific instruments. In this case, alongside technical considerations, the question of fair distribution of experiments between ESA member states was also a serious issue to be considered, as well as the competition and rivalry between laboratories and individual scientists. Three cases can be mentioned in this respect, as examples of the various aspects involved. The first is the harsh competition between two proposals for the most important of Giotto's instruments: the multicolour camera called to provide the first photographs of a comet nucleus. On the one hand there was the design proposed by the experienced team of the Jet Propulsion Laboratory who had built the *Voyager* camera: that same camera that in those very same days was sending pictures from Saturn of astonishing beauty and detail. And the principal investigator of the JPL proposal for Giotto was one of the most influential French space scientists, Jacques Blamont. On the other hand there was the proposal of H. Uwe Keller, from the Max-Planck-Institut in Lindau, with a team of scientists from several European laboratories. In particular, in order to get a better chance to prevail in what appeared again as a Franco-German confrontation, Keller had appealed to Blamont's most authoritative rival in France, Roger Bonnet. In the event Keller's proposal prevailed by a narrow vote and we can rightly believe that the final argument against Blamont's strong case was this simple question: "Why send a European spacecraft to the Halley comet and let the Americans take the pictures?"

The second case regards the plasma analyser. For this instrument, an English scientist from the important Mullard Space Science Laboratory, Alan Johnstone, had secured the best position.

He lined up a fairly good international team, including a German group from Lindau which could have been its main competitor, and he was a member of the ESA Solar System Working Group called to make the selection. Here however his instrument had to confront a proposal from Henri Rème of the Space Centre in Toulouse, prepared with a group from Berkeley and originally proposed for the NASA/ESA mission. The final vote was 50:50. The situation was embarrassing, and the outcome of the camera story did not make it easier. It was clear that strong pressure existed for France being granted a significant role in the group of Giotto principal investigators. Johnstone and Rème then arranged a deal between them: the former would limit his experiment to the measurement of fast positive ions while the latter would measure electrons and slow ions. The selection committee was happy to accept the deal and so Giotto carried two plasma analysers, with both Johnstone and Rème in the role of principal investigator.

Finally, there was the case of the experiment to measure energetic particles. This was not comprised in the Giotto model payload, as high energy phenomena are not associated with comets, and in fact it was originally discarded by the selection committee. Its eventual inclusion was mainly due to the wish to have in Giotto a principal investigator from Ireland, the last acquisition in the ESA European family. In conclusion, while claiming that the scientific merit and technical soundness of the various experiment proposals had certainly been taken into due account, the ESA executive could rightly feel satisfied that Giotto would carry to Halley four experiments from Germany, two from France, two from the United Kingdom, one from Switzerland and one from Ireland, with the Italians well represented by five co-investigators in four experiments.

This last consideration brings us to the next point, namely geography. A good measure for "bigness" in this case might be the distance between the experimenters and their instruments at the moment of data-taking: 150 million km. This would not be fair, however. Nevertheless, it is true that the building of Giotto involved scientific and technical staff in laboratories and industries spread over most of the European continent and the United States; that the launching of the spacecraft took place in French Guyane; that tracking and data collecting involved ground stations from Australia to California; and that Giotto's position in the Halley fleet implied close links with Russia and Japan. And even if we look at the individual scientific experiments, the teams involved in their realization were multinational in all but one case, and six of them included an American group. In this respect, Giotto's was indeed big science, with its characteristic pattern of long-distance telephone calls, frequent travels of most people involved, meetings of all kinds of scientific and technical working groups, and international symposia in exotic places.

Giotto was also big from the point of view of time scale. Contrary to most ESA scientific missions, the decision-making process which led to its inclusion in the Agency's programme was rather short, as we have seen, but it drew on the preceding two years' preparation of the NASA/ESA cometary mission. It then took five years from approval to launch (July 1980 - July 1985) and 8 months before the encounter with Halley and the start of data analysis. For the scientists already involved in the original NASA/ESA project it was a more than 10-year involvement, certainly a significant fraction of their scientific career ("you can only do this once in your life", as one of the principal investigators commented later).[5] And for those who came later the mission was an important element in defining their position and role in the space science community. We should also note that most space science missions last longer than Giotto. The latter in fact had its dramatic climax during the very short period of the encounter with Halley, while in general other missions provide scientific data continuously for years.

Our last point regards people and management (Figure 1). A clear distinction should be drawn in this respect between the management of the Giotto science and the management of the Giotto project. The former was the responsibility of the principal investigators and co-investigators for the various experiments, namely scientists working in laboratories outside ESA. They met twice a year on average, in the so-called Giotto Science Working Team. The latter was the responsibility of the Project Manager, who was an ESA engineer based in the Agency's technical establishment (ESTEC) in Noordwijk, Netherlands. A scientist from ESTEC's Space Science Department acted as Project Scientist, whose task was to provide an interface between the principal investigators, scattered all over Europe, and the Project Management Team in ESTEC. The overall responsibility for the mission, which also included the coordination with other missions to Halley, belonged to the Agency's Director of Science. This situation reflected both a peculiarity of space research *vis-à-vis* particle physics and a peculiarity of the ESA functioning *vis-à-vis* NASA. Unlike particle physics one can hardly recognize a well defined scientific leadership in Giotto. All experimental teams were relatively independent from one another in designing and building their instruments, in funding and managing their activities, and in analysing data and publishing results. And unlike NASA missions, they were also independent from the space agency which made the mission possible and whose flag ultimately appeared on the spacecraft. No formal contract existed between the Agency and the various principal investigators. In the words of Giotto's payload manager,

5 H.U. Keller, interview with A. Russo, 10/6/93.

> We have documentation that we give them, which places our requirements. And then we do it by negotiation. And it's negotiation, force of personality and everything else that determines what happens from then on.[6]

Realizing a Giotto experiment was certainly not simple laboratory science. It often implied the intelligent coordination of many people from different laboratories in different countries, and the management of important industrial contracts for implementing sophisticated technologies. Each experiment, however, was self-consistent, with its own scientific objective and its own technical hardware and data handling. No kind of scientific integration or data correlation was foreseen *a priori* and each group kept the property of its data. It is hard to find among Giotto publications papers with the very large authorship that are common in experimental particle physics. Sometimes the requirements for the various experiments conflicted with each other, which required reaching compromises in order to achieve the best results. This was the case when the Giotto principal investigators were called to decide on the distance from the cometary nucleus at the moment of closest approach. The camera team wanted to stay around 1000 to 1500 km in order to get the best pictures and to protect the camera from the hardest hit of cometary materials. The experimenters interested in measuring the physical parameters of the comet atmosphere wanted to go as close as possible. Others were indifferent. According to one of the principal investigators, "it was really a memorable conference" when this matter was discussed, with the ESA director of science on the phone from Moscow where he was for the Vega encounter.[7] In the event his was the final decision, following a compromise agreed on at the meeting, and Giotto was targeted at 550 km from the nucleus.

What was really big management, however, was the building and testing of the spacecraft, and the assembly, integration and testing of the scientific payload, within extremely tight constraints of size, mass and power, within the financial resources available, and within the rigid time schedule imposed by the gravitation law which was leading the comet towards the earth's orbit. And this kind of management, which mainly involved managing important contracts with industry, was the responsibility of the project manager David Dale and his team of engineers. They interviewed each principal investigator at the moment of payload selection, in order to provide the Solar System Working Group with technical assessment of the experiment proposal and of the capacity of teams to build them. They participated in all meetings of the Science Working Team and most discussions at these meetings, in fact, involved technical rather than scientific matters. The experiments had to be designed and built according to technical constraints

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6 J. Credland, interview with J.W. Warnow, 23/4/93.

7 F. Neubauer, interview with J. Genuth 14/5/93.

specified by the project management, and the project manager always had the last word in all important issues regarding the actual implementation of the project. As one of the principal investigators, H.U. Keller, recalled later:

> There may be a vote but this is not binding in a sense, it's still a recommendation, because those things are essentially decided by the hardware site. Because most often it involves resources or spacecraft safety. [...] The scientists have the power, only the power to make recommendations; the resources are really handled by the project, by the technicians and managers, because they have the money and they have the say.[8]

And Keller himself recalled how Dale forced him to use titanium screws in order to save some 50 gr out of his 13 kg instrument in one ton spacecraft.

The defence of the scientific objectives *vis-à-vis* the project management was entrusted to the project scientist Rüdiger Reinhardt, an ESA scientist not directly involved in any of the Giotto experiments. This was a very delicate function, given the traditional conflicting attitudes of scientists and project engineers, and it required great negotiating capability. It certainly did not imply scientific leadership, however, and in fact no clear scientific leadership is evident in the Giotto mission, such as can easily be recognized in all particle physics experimental programmes. Each team, in other words, was a self-consistent unity, whose experiment had only technical (i.e. mechanical, electrical, etc.) interfaces with other teams' experiments and with the spacecraft. Even though hundreds of people were actually involved in Giotto (Figure 2), we find again that its management was more a matter of engineers than scientists. And the success of the mission depended on the continuous negotiation between the various protagonists involved: the principal investigators, the project scientist, the project manager. In the case of Giotto, all negotiations went smoothly, and intelligent compromises could be worked out when difficult situations occurred. And the mission, in fact, was an outstanding success.

In conclusion, if a general lesson on space research can be drawn from this analysis of the Giotto mission, we should say that rather than speaking of "big science" it would be more appropriate to speak of "science in a big context". This means that in order to implement important scientific projects in space one needs large institutions which are not properly scientific; big technologies which are not specifically developed for research; considerable financial resources whose destination is however industry rather than scientific laboratories; complex management of engineering rather than scientific character. In other words, while

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[8] H.U. Keller, interview with A. Russo, 10/6/93.

CERN, the *Gargamelle* bubble chamber, the LEP accelerating facility and the UA1 detector are designed by scientists and only used for scientific research, the same cannot be said of ESA, spacecraft technologies, the *Ariane* rocket and ESTEC staff. It is this large-scale political and technical context that makes space science possible. Science, however, is far from being of primary importance, and while space research needs such a context, it could well exist without science.

Table 1. Giotto's scientific payload

Experiment		Mass (kg)	Power (W)	Data Rate (bit/s) Format 1/2/3*			Principal Investigator	Main Collaborating Institutes (hardware)
Camera		13.51	11.5	20058	20058	723	H.U. Keller, MPI für Aeronomie, Lindau W. Germany	Laboratoire de Physique Stellaire & Planétaire, Verrières-le-Buisson. Institut d'Astrophysique, Liège. Istituto di Astronomia, Padova. DFVLR, Oberpfaffenhofen. Ball Aerospace, Boulder.
Neutral Mass Spectrometer	M-Analyser E-Analyser	12.70	11.3	4156	4156	—	D. Krankowsky, MPI für Kernphysik, Heidelberg, W. Germany	Physikalisches Institut, University of Bern. Laboratoire de Géophysique Externe, CNRS, Saint-Maur. The University of Texas at Dallas.
Ion Mass Spectrometer	High Energy Range Spectrometer, High Intensity Range Spectrom.	9.00	6.3	3253	3253	1084	H. Balsiger, Physikalisches Institut, University of Bern, Switzerland	MPI für Aeronomie, Lindau. JPL, Pasadena. Lookheed Palo Alto Research Laboratory.
Dust Mass Spectrometer		9.89	9.1	2891	5782	—	J. Kissel, MPI für Kernphysik, Heidelberg, W. Germany	
Dust impact Detector System	Meteoroid Shield Momentum Sensor, Impact Plasma & Momentum Sensor, Capacitor Impact Sensor	2.26	1.9	361	903	—	J.A.M. McDonnell, Space Science Laboratory, University of Kent, Canterbury, UK	Rutherford Appleton Laboratories, UK. MPI für Kernphysik, Heidelberg. ONERA/CERTS/DERTS, Toulouse. ESA Space Science Department. Istituto di Fisica, Lecce. Istituto di Fisica, Bari.
Plasma Analysis 1	Fast Ion and Implanted Ion Sensors	4.70	4.4	3975	1265	1355	A. Johnstone, Mullard Space Science Lab., Holmbury St. Mary, UK	MPI für Aeronomie, Lindau. Istituto Plasma Spaziale, Frascati.
Plasma Analysis 2	Electron Electrostatic Analyser, Positive Ion Cluster Comp. Analyser	3.21	3.4	2530	1807	904	H. Rème Centre d'Etude Spatiale des Rayonnements, France Toulouse,	MPI für Aeronomie, Lindau. Space Sciences Laboratory, Berkeley.
Energetic Particles Analyser		0.95	0.7	181	181	181	S.M.P. McKenna-Lawlor, St. Patrick's College, Maynooth, Ireland	Dublin Institute for Advanced Studies, Ireland. MPI für Aeronomie, Lindau.
Magnetometer		1.36	0.8	1265	1265	407	F.M. Neubauer, Institut für Geophysik und Meteorologie, Köln, W. Germany	Institut für Geophysik und Meteorologie, Braunschweig. Laboratory for Extraterrestrial Physics NASA/GSFC. Istituto di Fisica, University of Rome.
Optical Probe Experiment		1.32	1.2	723	723	—	A.C. Levasseur-Regourd, Service d'Aéronomie du CNRS, Verrières-le-Buisson, France	Laboratoire d'Astronomie Spatiale, Marseille. Space Astronomy Laboratory, University of Florida, Gainesville.
Radio Science Experiment		—	—	—		—	P. Edenhofer Institut für Hoch- und Höchstfrequenztechnik, W. Germany	Radioastronomische Institut, Universität Bonn. DFVLR, Oberpfaffenhofen
TOTAL		58.90	50.6	39393		4654		

*Format 1: from CA—70 h until CA—1 h Format 2: from CA—1 h until CA+1 h Format 3: during cruise phase (CA = Closest Approach)

From: *ESA Bulletin*, n. 46, *Giotto Special Issue*, (May 1986), p. 42.

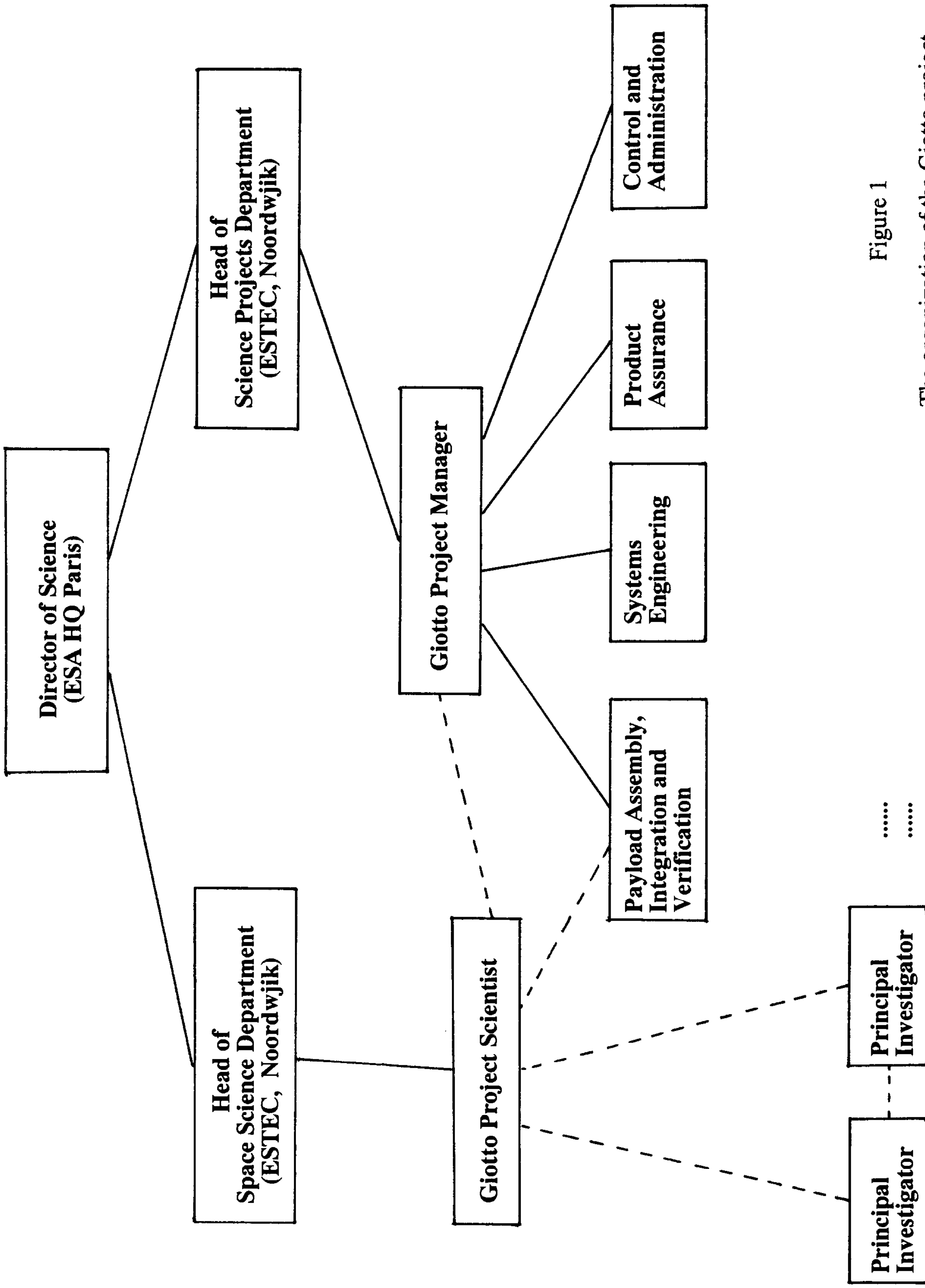

Figure 1

The organization of the Giotto project

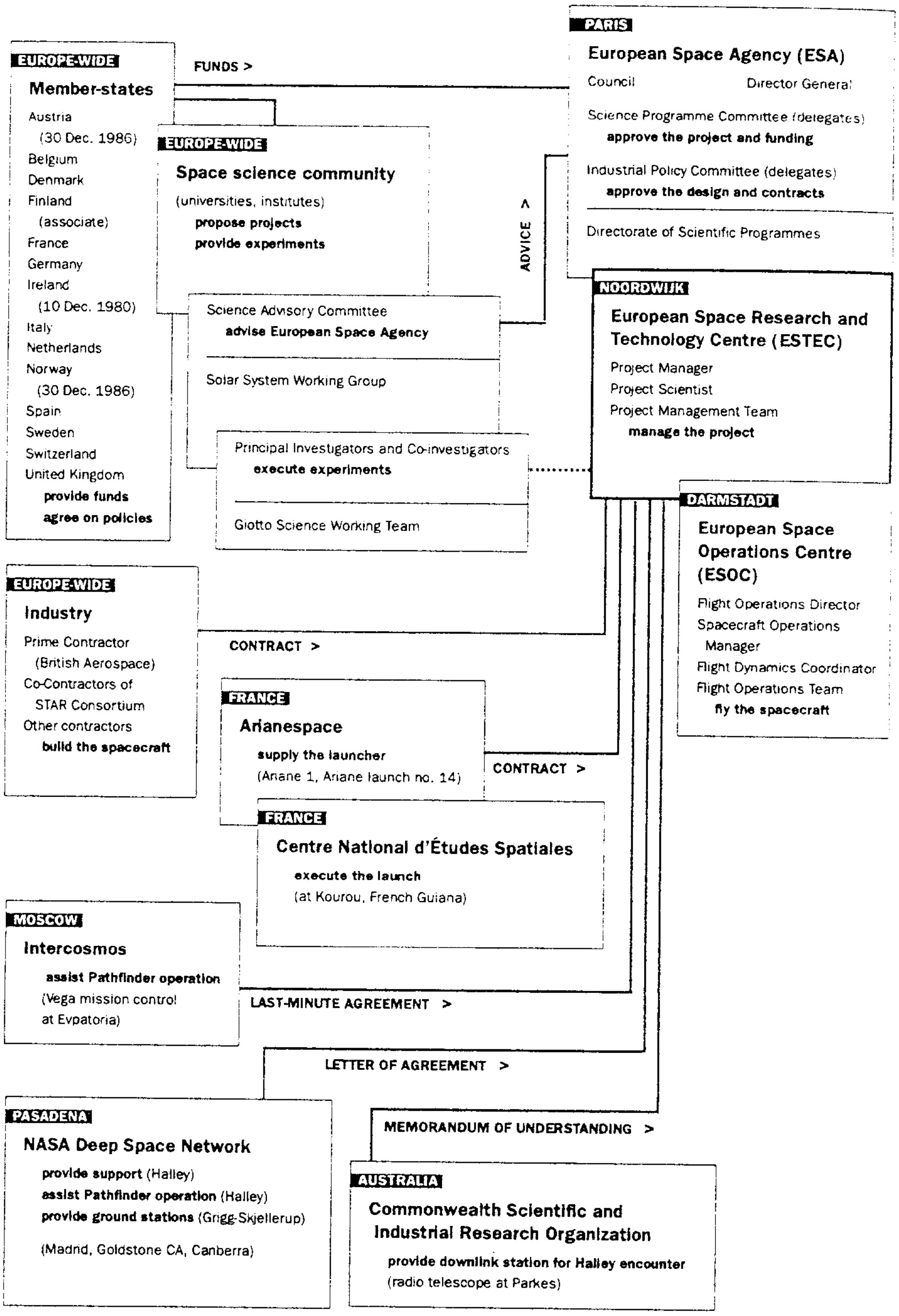

Figure 2

The organization of the Giotto mission. All lines converge on the project management at ESTEC. Contractual arrangements of various kinds were made with manufacturers and with other space agencies. The relationship with scientists (dotted lines) was close but not contractual.
(From: N. Calder, *Giotto to the Comets*, London: Presswork 1992, p. 220)

European Space Agency
Agence spatiale européenne

Contact: ESA Publications Division
c/o ESTEC, PO Box 299, 2200 AG Noordwijk, The Netherlands
Tel (31) 71 565 3400 - Fax (31) 71 565 5433