Invited Paper 1.2.

THE CONTRIBUTION OF SCIENTIFIC RESEARCH TO THE DEVELOPMENT OF THE PHOTOGRAMMETRIC SURVEY METHODS

L. SOLAINI

Director of the Istituto di Geodesia, Topogr. e Fotogrammetria, Politecnico, Milano

1 The subject of this meeting is the technical and industrial organization of a photogrammetric enterprise: therefore, the specifical problems of scientific research are beyond the purpose of our lectures and discussions.

However, since we are dealing with a modern and highly specialized industry, such as photogrammetry, I believe that science is not to be disregarded and that its voice should be heard, because science is the necessary frame on which all rationally conceived techniques should rest.

I am perfectly aware that I am saying an obvious thing, since the necessity of scientific research is now widely recognized in all fields of industry and technique; however, photogrammetry has some peculiar traits that are worthwhile pointing out.

The public and private photogrammetric enterprises never reach the dimensions of a large industry; they often are small and almost crafty firms, while only a few ones can be considered medium size industries. Therefore, they cannot usually establish their own research centers and labs; there are only very few and internationally known exceptions to this rule. There follows that the scientific research is mainly carried out in the universities or in some other specialized centers whose characteristics, however, are much similar to those of the universities.

This fact gives rise to several drawbacks: some of them are peculiar of the free research; the other ones come from the insufficient contact between university and industry which sometimes ends up to antithetical conceptions, such as the rejection of all practical problems on the one side and, on the other, a fearful suspicion toward all scientific activities which are considered as being too far apart from the problems that an industrialist has to cope with daily.

Since basic research, even when completely abstract, must be carefully safeguarded also for its eventual practical applications in the future, the incomprehension on the part of industry is always harmful, even if in some cases it can be justified and understood. In the first place, it deprives the technicians of remarkable help, secondly it prevents them from acquiring a sound cultural background (that should be constantly kept up to date); finally it keeps scientists away from a lot of problems to which they could give the contribution of a rational postulation and a logical solution, generally much simpler than those empirically devised.

I don't want to give the impression that serious contacts between research and application are lacking today: it would not be true. I only wish to stress the increasing necessity that they become as generally widespread as possible, not only in the large enterprises where real scientists of international fame are at work, but also in the small industries that cannot afford it.

I will now try to examine, even within the narrow limits of time allowed to a lecture, what are the fields in which the collaboration between science and technique can be better established, and the best methods to make it efficient. I will not be able to avoid an overlapping with the subjects dealt with by the other speakers and I apologize in advance: however I shall try to confine myself to the relationship between science and technique, without entering into organizational or strictly technical problems.

2 Since I believed it to be of great importance. I will now summarize, briefly, the funda-

mental stages of scientific photogrammetric development, at least those which mostly advanced the application.

Let us remind firstly the initial geometrical studies, among which those of Mr. Finsterwalder are upstanding and which thoroughly clarified the projective properties of photograms and mainly those of pairs of photograms, opening the way to such a fruitful concept as relative orientation; the problem of external orientation, that has inspired an enormous number of works and in which Mr. von Gruber, the master that he was, has established rules which are still valid; the detailed analysis, sometimes almost crude, of plotting instruments and of their operating conditions, which has certainly greatly contributed in giving new ideas and suggesting improvements to their constructors; the studies on the accuracy of photogrammetric surveys, which have firstly permitted the universal affirmation of the new survey method in spite of strenuous reservations and oppositions, and then have brought to the evaluation of what photogrammetry can give in the various operating conditions, to the selection for each survey of the most convenient methods of taking and plotting, to the establishing of rules for the control of the map accuracy and for testing.

There followed the problems of aerial, radial and, particularly, spatial triangulation; this latter has opened a wide new field of technical and experimental investigation and these studies are still intensely pursued.

We all recall the classic paper of von Gruber, establishing the first rules for strips adjustment; the incertitudes and delusions that for a long time have troubled the scholars on account of the mysterious « breakings »; the first doubts that the accidental errors might have an importance never thought of before; the flourishing of numerous methods of adjustment, one better than the other in theory, while in practice they all proved to be equally weak; the introduction of auxiliary elements, their long abandonment and the new 'interest they now arise; finally, thanks to the widespreading of the electronic computers, the introduction of so many block adjustment methods.

In the field of block adjustments we have experienced a very similar situation of what happened for strip adjustments, that is to say, many procedures have been developed and, inevitably, discussions have arisen on their degree of flexibility, on their soundness, on their economic competition.

These discussions, even though they were not always entirely objective, have already led to practical results of great importance, thanks to the noteworthy development, in concept and application, of the theory of errors, and to the possibility of utilizing very sofisticated mathematical algorithms.

Further, they have shown the necessity of a deeper study of the photogrammetric process, of a detailed examination of its structure, of a criticism of the various operations. Their purpose and their goal is that of understanding, in the most thorough way, the mechanism by which the errors in the various phases of taking and plotting occur, and to establish the working procedures and especially the adjustment methods with more accuracy than is possible today.

In other words, we partially revert to the beginning of the photogrammetric studies, but with a wealth of experience and with much more refined mathematical instruments. On the other hand, theoretical studies proceed side by side with an intense experimental activity, individual and in collaboration; these last researches constitute an indispensable element in an applied science such as photogrammetry. I wish to stress especially the experiments performed by international collaboration under the auspices of I.S.P. and O.E.E.P.E., since they were made not only by Universities and research Institutes, but also by industrial organizations; thus representing a direct contact between science and technique, research and application.

3 Let us now further look into the subject of this lecture, by examining the principal fields in which scientific research contributes to a sound development of industrial activities and the ways by which this contribution may be increased.

I shall briefly deal with the problems of the training of personnel, of the selection of instrumental equipments, of the formulation of the most inclusive plans of surveys, of the very execution of the survey in its various phases and, finally, of testing operations.

To consider a problem such as that of personnel training, coupled with that of research may seem strange and not pertinent. Actually it derives from the fact that the instructors must also be researchers, a thing which is normal in all universities. However, it is my opinion that for what concerns photogrammetry it would not be sufficient to employ well qualified teachers for the training of the executive personnel (graduated people) but also for the training of skilled technicians who, especially in Italy but, may be, also elsewhere, are taught only how to perform certain operations, without giving them a more coherent and wide, however limited, vision of the fundamentals of photogrammetry, of why the various operations are performed in a certain way, of why certain results are obtained, and so forth. To give a photogrammetric operator a reasonably adequate background does not require a very long time and has instead a human and productive value which largely repays for the expense involved.

A photogrammetric technician must feel himself consciously collaborating in the production of his firm, he must feel convinced that he is not only giving a purely mechanical activity but an intelligent and, within the sphere of his duties, an equally valuable collaboration as that of the executives.

Only under these conditions his work will be carried out with assurance and enthusiasm, thus deserving the full trust that any employer should be able to give all personnel.

Such a kind of teaching cannot be given only on the ground or in the plotters room, since it requires theoretical instructions and practical exercises that should not be simple training but study, under the guidance of teachers capable of discussing results with the students, recalling the general principles, so that theory and practice shall merge in the student's mind, and the former should not only be a sequence of formulae and notions almost void of any meaning.

The teaching to graduate students is naturally more complex in view of their future activity as technical executives of a firm or of one of its sections. Therefore, the theoretical instruction becomes preeminent, and must be imparted in the most complete and modern way, such as to consent the application of the mathematical proceedings used not only in practice, but also in research work, to allow the use of the theory of errors, without incertitudes, in evaluating the accuracy and in performing adjustments. Moreover, a deep and not only descriptive knowledge should be acquired of the equipments, of the various procedures, of the large number of problems, sometimes very complex, that the photogrammetric survey presents.

In other words, a photogrammetric engineer is the key element of an industrial enterprise and the connective link with researchers. He must then be in a position to keep up to date with the results of even the most abstract research, to present to the scientists the new problems that professional practice incessantly creates to an alert and skilled mind, to discuss them and, in several cases, to help in their solution.

I don't think that this is a professor's utopia: industry needs well qualified technicians in all its branches, and photogrammetry does not make an exception to this rule.

Universities, in general, do not give sufficient preparation and a post-graduate specialization is necessary that does not need to have an educational character, but may be acquired from research institutes. In fact, the students already have a general scientific maturity and are almost ready for individual study; furthermore, long individual contacts with scientists establish a relation of cultural and human interests, extremely useful to the future collaboration. I had some personal experience in this field with quite satisfactory results.

I am not sure that the ideas I exposed are in accordance or contrary to those that prof. Schermerhorn will more thoroughly deal with in his lecture. I purposely left out all details of professional preparation, since this was not my task. I repeat that the foregoing only reflects my opinion of the necessity of a close collaboration, at various levels, between centers of studies and photogrammetric enterprises, especially in the interest of the latter.

4 The evolution and perfecting of the taking and plotting equipment are mainly the achievement of industry and of some men remarkable for their ingeniousness. However, there are also some very important instruments, conceived and studied in research labs, and some other instruments, even very recent ones, the fundamental principles of which have been derived from theoretical studies. But this is not the main contribution given by researchers: it consists,

rather, in the serious experimentation that the scientific Institutes have carried on with no pause, for more than forty years in a direct or indirect fashion.

By direct experimentation I intend the study of the intrinsical qualities of the instrument, of its stability, of its accuracy, of the possibility and convenience of its use for certain procedures, and so on. I do consider this work of analysis, of sometimes quite hard criticism, a valuable collaboration given all manufecturers, because it shows to all and not only to those who have realized a certain instrument, the solutions which appear to be brilliant and those which are not, the faults that must be corrected, the unnecessary limitations that may cut down the total efficiency of an instrument, it may even sometimes suggest changes or new solutions.

Indirect experimentation consists in the study of certain special procedures, therefore, allowing an evaluation of the instrument used; it has, perhaps, an even greater importance for the operators, since the equipment is studied in operation, that is to say under conditions often very similar to those of normal work, thus supplying a simpler and more precise criterion of choice.

I agree that it is not easy to deduct these criteria from individual experimental researches; it is rather the global experience which engenders a general evaluation of the applications of each group of instruments and achieves in giving very accurate suggestions to those who must supply a photogrammetric industry with an armonious series of equipment, answering the needs of its production.

The choice is much easier for public enterprises with a well defined task than for the private ones, which cannot confine themselves to a strictly specialized production, but must be ready to cope with both the urban maps at large scale and the medium scale maps of wide areas.

A great flexibility is needed in the last instance, reached without exorbitant expenses for the purchase of instruments which are often badly, or even not utilized; the equipment to be installed must, therefore, be planned with great carefulness, without prejudice, taking into account all elements at one's disposal, without disregard for those that scientists, by their patient work and their impartial judgement have gathered in the labs.

5 The study of a survey program has acquired a greater and greater importance, as a consequence of the industrial development of photogrammetry and, therefore, of the economic competition which has become very serious, so that only the well organized and intelligently guided enterprises can survive.

With a few exceptions, we can say that for some time, the technical problem of producing a photogrammetric map, complying with the most severe requirements, has been overcome. What must now be achieved is the construction of a map really meeting the required specifications, in the shortest possible time and with the least possible expense. In other words, it is an essentially economic problem, that must be solved by technical means, step by step, through the choice of the most suitable procedures.

A competition based on lowering the prices down to the limit of the production cost, or even below it, in the hope of realizing, during the production process, some more or less scrupolous economies, is not a competition which can be conceived at an industrial level, since it inevitably leads a firm to extremely critical economic situations.

The true, sound competition, capable of stimulating progress and technical improvement, consists of studying, case by case, the most appropriate operating means keeping into account the latest, whenever sound, achievements of technique and scientific research. This is the reason why I have previously stressed the necessity that the executives of a photogrammetric firm be well prepared, and always up to date also technically.

The danger of relaxing on the usual survey plans, on crystallized ideas, considered intangible, is serious whenever there is no time and no one in the firm capable of studying, of thinking and of trying.

Presently, important works are contracted by international bids; quite often, specifications are established in the tender, but the competitors are left free to suggest changes or improvements. This collaboration is rightly requested because the initial program is drawn up by a man who well knows, or at least should know, that he is not the only person versed in

photogrammetry and who, therefore, asks the opinion of other qualified men, in the common interest. This collaboration must be offered with the widest frame of mind, without fears, when one can rely on the competence, on the open-mindedness and even on the objectivity of judgement of the customer.

I well know the esitation of him who has to offer plans different from those specified in the tender; on this subject there would be a lot to say, but it does not pertain at all to our lecture and, therefore, allow me to be brief on this matter but to insist once more on the necessity of a thorough study of the suggestions to be advanced, of a logical and technically perfect formulation of the reasons leading to the proposal of a certain plan, of the intimate conviction of being right, which may only derive by coupling culture to experience.

Aside from the problem of international bids, however essential for large size enterprises, all surveys require much flexibility in the preparation of programs, starting from the selection of the average photogram scale, to the setting of the ground points, to their determination, to the eventual employment of aerial triangulation, to the plotting procedure, to the decision of whether or not some further measures on the ground should be made.

The experimental researches carried out by I.S.P. and O.E.E.P.E. give elements of great interest: today it is known for sure what is the accuracy that may really be reached in plotting at large scale both in the absolute position of points and in their relative position; it is known what one may expect from the execution of blocks by means of aerial triangulation, both at large and small scales, while the answer to the problem of the most suitable size for intermediate scale blocks (1:10 000, 1:20 000) is still under study.

The introduction of tellurometers has radically changed the procedure used for the determination of the ground points; analytical and numerical photogrammetry permits to rapidly solve problems of special character, such as trose relative to surveys for road planning, land reclamation, precision, cadastrial mapping, and so on.

The application of the photoplans and automation will finally lead to considerable changes in the plotting procedures: these are today in an initial phase and once more a wide and systematic experimentation will be necessary, in order to give the users the required elements to decide when and within which limits the new procedures might be adopted.

Of course, the flexibility of the methods requires a lot of equipment and, consequently, remarkable installation expenses, which may be borne only by the largest enterprises. It is not up to me to discuss these topics that will be dealt with by prof. van der Weele: but I cannot help stating my conviction that industrial concentration or direct collaboration between several firms becomes more and more indispensable also in photogrammetry. On the other hand, it is always possible to turn to the help of research centers which may usefully collaborate to the study of programs, to the execution of some especially complex measures (i.e. analytical aerial triangulation), to the preparation of intricated computations and so on.

One might say that this consulting work involves time and personnel that should be solely devoted to study. That is true; however, it has the advantage of keeping them in constant contact with the real problems of photogrammetry and of stimulating ideas for research.

6 Another essential element to the good operation of a photogrammetric firm is its orderly internal organization and the strict observance of the rules established for control and maintenance of the equipment, that should never be overlooked, no matter how urgent the work.

Even in this purely organizational task, the scientific mentality, accustomed to a rigid and logical behaviour, has a remarkable importance. In other words, it is necessary to apply all useful rules but, at the same time, to reject the useless ones; of course, in this task, one should thoroughly know one's equipment, all studies concerning same, so as to gain by a rational method a wide experience on the operation of the instruments. This does not involve scientific research, but rather the application to practical instances of the method or, even better, of the experimental spirit.

A word must be said about computations, so necessary in photogrammetry whenever the numerical and analytical procedures are adopted.

The use of digital computers should become a general habit, even when it would not seem strictly necessary. As far as I know, these powerful means of computation are frequently discarded because programs are difficult to prepare, only a few large enterprises can afford to own a computer and, finally because of the habit of following the traditional methods of computation.

Nowadays, alla programs concerning topographical and photogrammetric operations are available. Should some different ones be needed, the modern systems of coding are so simple that they certainly do not represent a great difficulty for anybody. Computers are so widespread that any enterprise can have them at its disposal whenever necessary.

Finally, we must bear in mind that electronic computations are extremely faster and cheaper than the usual ones; at the same time they can easily supply many more additional data.

A trivial example is that of the determination of the ground points by means of multiple resections: the electronic program computes in a few seconds the points coordinates by means of the least squares procedure, together with their mean square errors.

Besides, I will recall the programs executing the absolute orientation, an extremely valuable tool in numerical photogrammetry; the special applications that I have previously mentioned, with reference to the evalutation of areas in road planning; the adjustment of strips and all the computations needed by analytical triangulation.

One could ask what is the relationship between the above considerations and scientific research. Even if it is true that, once established, each procedure becomes « routine », we must not forget that behind each program there is a lot of scientific work for choosing the most suitable algorithms and the best approach to each kind of survey. Is is a work involving a continuous process of refinement and criticism that directly derives from scientific research.

Besides the electronic computation procedures, which are already regularly and extensively used, we should also consider many other programs that are still under way, among which those concerning the evaluation of the accuracy of an aerial triangulation adjusted by means of blocks, the most appropriate distribution of the ground known points in view of the adjustment, and so forth. The last researches have led to quite unexpected results, which are of a considerable interest for their practical applications; by theoretical investigations it has been found that the ground known points placed in the middle of a block are practically useless for its planimetric adjustment; whereas these placed on its borders are the only ones that are taken into account. This result must still be experimentally confirmed, but it will deeply change the practice by simplifying the operating procedures.

At last, I would not hesitate to call scientific the sound organization of the work, which shall permit the photogrammetric operator to check each phase of a survey, so that its progress will proceed with no possible error. In other words, the surveyor should be the first tester of his own work, both because he must be sure that the maps he will deliver to his customer are correct and, secondly, because from a critical examination of the obtained results he will draw valuable information for the improvement and simplification of the procedures. But, here too, the examination of results is an essentially scientific work applying, with no doubt, the methods of analysis, the criteria to evaluate the accuracy and also the experimental achievements proper of scientific research.

I belive that it would be very useful practice to complete all surveys with a technical report, containing all elements necessary to evaluate the work done: such a report is compulsory in many fields of engineering and I don't see why it should not be done in a work so complex and delicate as a photogrammetric survey.

7 Let us now come to the final phase of a survey, that is the testing. It is a subject which has not yet been well clarified and that often gives rise to misunderstandings and arguments.

First of all, the criteria of evaluation of the accuracy of a map are established case by case, whereas, now that the surveys assigned after an international bid are more and more frequent, it would be advisable to agree on a common method.

There are instances, in fact, in which the principle is adopted that, in order to obtain a certain map, one should use photograms at a certain average scale, which is fixed in the

contract. The formulas of tolerances are then established on the basis of the accuracy that can be reached in these conditions: they are derived from experimental results and from numerous data of previous testings. In other instances, the criterion is applied that a map at a certain scale that should serve certain purposes, should have a preestablished accuracy: it is then up to the contractor to see how this accuracy can be reached.

In some cases the mean error of the spatial position of a pint and of the height of a contour line are fixed; in some other ones, the tolerances, that is the maximum acceptable values of these errors are established. Very often mean errors and tolerances refer to the position of points, i.e. to their coordinates referred to a common origin: in such a way the absolute accuracy of the map is the criterion of evaluation. On the contrary, sometimes, the relative accuracy is taken into account, while the absolute accuracy is somewhat disregarded (for instance, the distance and the difference in height is measured between points on contour lines placed in the same area).

Furthermore, there are contracts that embody the testing of the accuracy of certain operations, mainly those relative to the determination of the ground points for the photograms orientation, whereas other contracts are only interested in the final results.

Finally, there are differences also between the various methods of evaluating the correct topographical interpretation of the photographs, which has a greater and greater importance considering the more numerous applications for which a map is employed today. Therefore, the mere geometrical information is no more sufficient and the kind of interpretation which is possible in a photogrammetric survey much better than in the usual topographical one, is required today by all structural engineers and is of a considerable help in the work of actual photo-interpretation.

It is not my intention to examine all these various criteria and to discuss their degree of validity. I agree that it is difficult to reach the complete uniformity because it is not possible, in such a delicate field, to impose on the customers to give up their freedom of judgement.

I only wish to remark this rather caotic situation and, therefore, to suggest the opportunity that scientists intervene in this field in a way more organic, deep and organized than they have done so far. The International Society of Photogrammetry is certainly the most suitable instrument for such a task and the establishment of special study groups should be welcome by everybody. This is, in my opinion, one of the fields in which scientific research has given, so far, very little contribution, but much more may be done in the future.

We should now consider the figure of the tester and to delineate his task. Presently, there are two ways of proceeding. In one of them the tester intervenes only at the end, when the completed map sheets are presented to the customer who makes his own controls and, on the basis of same, accepts or rejects the map, and, in certain cases, demands that part of the work be made over. In the second case, on the contrary, the tester follows all phases of the survey with the operator, checks them one by one, helps the firm performing the survey with suggestions and advice and, in some instances, tries to solve unforeseen problems that often arise.

Both methods have their advantages and disadvantages; the second method requires. from the tester a far greater work than the first one and a thorough knowledge of photogrammetric proceedings. Therefore, the tester must be selected within a very narrow group of highly skilled technicians, which constitutes a difficulty. It becomes practically impossible to use this second method of testing when, for instace, customer and contractor belong to different countries.

However, this proceeding is, in my opinion, far superior to the first one, since it puts at the side of the operator a very experienced person, who acts rather than as an inspector, as an adviser and collaborator in the highest sense of the word. He further eliminates long operations on the ground, since the photogrammetric survey, contrary to the ordinary topographical one, may largely be checked in the offices. Finally, he intervenes at any time he deems proper, thus preventing bad results in the survey, difficult to correct and time-consuming.

Even from this point of view I think that testing rules, embodying various but well devised and clearly stated methods, might represent a very useful contribution of the I.S.P.

8 Let us try to draw some conclusions from what I said so far. The contribution that scientific research has given and gives to the development of photogrammetry and of its technical means is, in my opinion, out of doubt. However, it is not only by innovation that research helps technique, but also by its continuous work, which sometimes appears to be slow, but always clarifies ideas. To clarify ideas requires one of the major efforts from the scientists and the product of this effort is offered to the technicians to their great advantage; in turn the latter assist the scientists with the information coming from a wide and unique experience.

Similar collaboration is in act and may always be noticed in conventions, meetings or group research.

As in all fields, scientific and technical papers are much too numerous. However, a scientifically well-rounded technician might and should keep abreast with specialized literature and select those works which describe important results and contribute to the evolution of the thinking in photogrammetry.

Another form of contribution is the training of highly qualified personnel and of the contacts that it has, and must increasingly have, with research centers.

The consulting work performed by researchers for photogrammetric firms should be increased, especially in those firms which cannot afford scientific personnel, thus putting them in a position of par with larger and more advanced enterprises in the intimate knowledge of all possibilities offered by photogrammetry. At the same time, this collaboration will permit the technicians to master new techniques, to get accustomed to look, in all cases, for the most appropriate solutions.

Finally, the National Societies of Photogrammetry can perform a work of connection, exchange of information, personal contacts, and can create that atmosphere of trust and of mutual esteem that becomes more and more difficult in our troubled era, but that our spirit needs so much.

The picture I have drawn is certainly an ideal one and shows the wishes, that not alfays can come true, of a scientist who always is somewhat like a dreamer. I would be happy if these words could produce a small improvement toward a better unity of the efforts of us all, teachers, theoretical and experimental scientists, survey operators and all those for which photogrammetry is not only a trade, but a task that enthuses and gives us a feeling of responsibility, since it is on our maps that many other technicians, relying on our work, study, plan, build.