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NEW HELIBORNE EQUIPMENT AND PHOTOGRAMMETRIC SURVEY TECHNIQUE

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Abstract

A heliborne pivoting support is illustrated which is specifically designed for close range stereo photogrammetry in engineering.

Industrial photogrammetry provides an extremely accurate and versatile method for noncontact, three dimensional (x,y,z) measurement of a whole of points on an object of interest.
The object can be almost anything from the size of a football to that of a football field, and even larger, and may be in motion or subject to continuous deformation, as a big structure during the daily thermal excursion.
Digitizing is made by comparing two photographs of the same object taken at the same time by two synchronized cameras put in two different places, but with the lens axis parallel to each other, the precision is a function of the images quality and of the subject distance vs cameras spread ratio.

The idea of using an helicopter as a mobile support for survey cameras meant to carry out an equipment, referred to as the SER photo System (R) and realized by Caproni Vizzola Costruzioni Aeronautiche, which is installed aboard an AB 412 Agusta helicopter and consists of a tubular structure equipped with two pods wherein the metric cameras are housed.
Means are provided to rotate the cameras, allowing to shoot photographs in any direction, from horizontal to top-down, giving then to the system a high degree of flexibility, thanks to the helicopter maneuverability too.
It is a sophisticated system that permits the accurate measurement of the distance between centres of offshore piper or the dimensions of moving objects.

Potential applications range from the inspection of offshore installations, surveys of large inaccessible buildings, to the monitoring of rapidly evolving natural phenomena.

As far as engineering is concerned, the system makes it possible to bridge the gap, in operational terms, between aerial and close range photogrammetry.
Also, the development of a new method of suspending the metric cameras - capable of shutting off excessive rotor vibrations - has enabled hitherto impossible surveys to be performed.
Research has been partly financed by E.C.C. aid under Contract TH 15.44/83 Italy.

1. FOREWORD

It is a well known fact that during the seventies the evolution in the construction techniques and design of marine structure led to an ever increasing application of photogrammetry in dimensional checks and 'as-built' surveys of petroleum platforms, with excellent results.
However, when the surveys must be conducted at sea, possibly on moving objects and in rapidly evolving, non repeatable situations, photogrammetry becomes inapplicable owing to its obvious limits.

The difficult problems of special surveys, which are infrequent but certainly not extraordinary, were approached from two angles:

- by realizing a heliborne photogrammetric platform to obtain images of the object from the best positions with no other limits than those given by the object's visibility and by the distance between the two cameras;
- by inventing a simple and effective procedure to create the necessary absolute orientation elements around and within the subject, without having to refer to a conventional network of trig points.

2. MOTIVATIONS FOR THE RESEARCH OF NEW METHODS

2.1 The construction of petroleum platforms on clusters

When the exploitation of an off-shore hydrocarbon bed is planned in an area where the sea is relatively shallow, there is no economic convenience in installing a 'Jacket' type platform, that is, reticular pyramid frustrum shaped structures which is expensive and complex.
In these cases 'monotubular' or pipe 'cluster' supports are preferred for the fixed production rigs (see Fig. 1).
This involves large size pipes which are driven into the sea-bed to a suitably safe depth and which break the water's surface to act as a number of supports onto which the platform (or deck) will be fitted to contain machinery, lodgings, facilities, heliport, etc.
To construct a structure of this kind one must first of all determine the exact centre distance between the pipe headers so as to design the above deck so that its leg stumps accurately fit the headers. Owing to the difficult environmental conditions of sea works, the opposite solution

(installing the pipes with great accuracy in project determined locations) is not feasible.

Thus the problem can be stated as follows:
Given 3 (or more) pipes, 2 to 3 meters in diameter, projecting above the sea surface for about 8 to 12 meters, and 20 to 50 Kms from the shore-line, one must determine the distances between the centre-lines of the pipe headers with a specified approximation of 1 to 2 cm. One should bear in mind that the centres are not solid and that a station is impossible. Also, the work environment could cause dangerous situations for the safety of personnel involved, even when using simple and inaccurate procedures (see Fig. 2).

2.2 Measurement methods studied

When, in 1978, AGIP set about to solve the problem, it became clear that an alternative solution to the traditional use of metal tapes was needed.
So, every possibility offered by topography and geodesy through instruments such as theodolites, tacheometers, electron-optical and electromagnetic diastimeters and coincident or stereoscopic collimation telemeters, was examined.
All these hypotheses had to be rejected for practical, operational, safety reasons, or for the lack of economy or accuracy.
In 1978, stereo photogrammetry also seemed in no way a possible solution.
In fact, on second thought, an accurate photogrammetric orientation needs an 'a priori' determination of 5 trig points, from the moment the topographer should manage to determine the first three points, (eg. the centres of the three pipes) the reason for and convenience of using photogrammetry would end.

3. OUTLINE OF THE NEW PROCEDURE

3.1 Evolution of needs and innovative ideas

During the years 77 to 81 there was a noticeable development in photogrammetric dimensional checks of prefabricated on-shore metal structures. Towards the end of 1981 this led to a re-examination of the problem from a new point of view.

First of all, determining the centre lines of the pipes was no longer enough. Also manufacturing defects, possible dents caused by blows, and errors in their vertical standing had to be checked.
Secondly, why determine the photographic scale by means of the usual rectilinear lengths which is difficult to realize at sea; why not by calibrating curved segments of known length, which is far easier to perform?

And again, why not try out a relative global orientation, that is to say, extend it to a full stereoscopic coverage, including both still and mobile structures or objects?
Moreover, why not exploit the chance to gather all the stereo photogrammetric, shooting instruments into a single device and then fit it on board a helicopter?
Wouldn't this have made the viewing of the subject from any point in space possible? Free from the operative and cost limits of any other kind of support such as ships, cranes, cherry pickers, or trellis masts.

The many tests and studies conducted by the AGIP Industrials Photogrammetry Unit proved that the new method could be applied only of a medium-large helicopter, featuring great stability and near absence of vibrations, was available.
Among the various existing models the AB 412 SP built by COSTRUZIONI AERONAUTICHE GIOVANNI AGUSTA SpA, was chosen.

3.2 Approach to the new solution

It is well known that a photogrammetric survey from the air normally takes place in clear atmosphere and (near) absence of wind. This last condition, together with a calm sea, is also the necessary requirement for any kind of engineering job on board a vessel at sea.
Therefore, clear atmosphere, absence of wind, and a calm sea can be considered the binding conditions in which also the special photogrammetric surveys at hand may be performed.
Conditions which are ideal for operations with any kind of aircraft.
The choice of an airborne point of view is a consequence of the limits of floating vessels (height from the sea surface and narrow steerage). Wanting to close-in to altitudes between 30 and 60 meters also leads to writing off airplanes and radio-controlled balloons.

So helicopters came forward as the only means which could feature enormous operative flexibility; one need only think of the possibility of thoroughly checking the trestlework of a petroleum platform for deformation which occurs during the launching at sea of the structure. In this way one can conduct a number of surveys of the subject, from a number of different angles, in a short time and at quite close range through with the safety afforded by the escape velocity of a helicopter in case of danger.
To solve the problem terrestrial cameras had to be innovated; they were adapted for use on an aircraft, and synchronized to ensure an accurate reproduction of the three-dimensional image of the subject; a suitable supporting structure to be fitted on board the aircraft had to be devised and a new survey procedure founded on the measurement of curvilinear segments by means of chains was also realized.

4. INSTALLATION OF THE PHOTOGRAMMETRIC EQUIPMENT ON THE HELICOPTER

4.1 Aeronautical aspects

The idea of using a helicopter as a mobile support for survey equipment only represents one of the possible extensions of all the feasible applications. The realization of this idea has brought the Caproni Vizzola Costruzioni Aeronautiche technicians to face and solve some rather difficult mechanical problems.
It is well known that helicopters are the most critical machines from the vibrations point of view; these are due both to the engines and, above all, to the interference in the aerodynamic flow between the rotor blades and the fuselage (one need only to think of the typical rhythmical beat of the rotor which is simply one of the effects of this phenomenon).
In fact it has always been difficult to fit photographic equipment, especially if it is precision equipment, on board this type of aircraft.

Therefore the problem consisted in mechanically insulating the photographic equipment from the fuselage, at the same time creating a supporting structure which would feature the sizable centre-to-centre axis required by the AGIP Industrial Photogrammetry Unit's specifications. The weight and size also had to be kept to a minimum so the assembly would not heavily hamper the craft itself.

4.2 The S.E.R executive project

The engineering solution adopted consists of a pipe transversely fitted to the helicopter which runs through the passenger cabin. At the ends of the pipe there are two pod-shaped containers for the photographic equipment (two metric UMK 10/1318 cameras synchronized by an impulse gun) and two range finders. The range finders are fixed to the cameras thus forming two units bound to the pod structures via spring and cushion devices while the viewing apertures in the pod shells are protected by vanishing doors.

The design and realization of the insulating mechanisms was a very exacting job, both because of the critical features of the structure (consider the pipe's elasticity; it projects from the fuselage and has a weight at both ends which causes bending and torsion stressing), and because of the limited space available inside the pods, which have to be kept relatively small to curb aerodynamic strain.

Considering the relevant sensitivity of images to angular vibrations, both along the axis and perpendicular to it, the optimization of a system that had to function through a wide range of frequencies, and had to control the three rotations in space, proved an extremely painstaking experience.

A further complication was the need to shoot both forward and downward, and through all the intermediate positions. The change of trim, which was simply realized by rotating the pipe round its axis by means of an electric actuator, finds a reverse feature in the complication of having a suspension which must respond to the shift in direction of the two photographic units' weight relating to the pods in which they are contained.
This is the feature that suggested the name for the supporting structure unit: S.E.R, Heliborne Pivoting Support R. It also includes the control and checking devices for all functions, the monitors which enable the photogrammetrists to suitably target the subject, and to check that the helicopter is stationary when the photograph is taken.

The S.E.R must be fitted on a medium/large helicopter which can carry not only the support itself but also the two photogrammetrists needed to handle the system. For the above mentioned reasons it must also feature a low level of vibrations, therefore a turbine model is definitely preferable.
Choice fell on the AB 412 SP model developed by AGUSTA with the collaboration of BELL. It is based on the AB 412 model and was realized to obtain a consistent reduction in vibrations without significantly modifying the successfully tested design of the earlier model.

The double blade rotor was replaced with a four-blade one of composite material with elastomer hub bearings and the introduction of a pendulum device for energy absorption. The result was a considerable reduction in the vibration level and consequent noise reduction and greater comfort for the passengers.

4.3 The helicopter adopted

The AB 412 SP is an aircraft which was specially conceived for passenger and off-shore transport; it is a long range, fast and roomy helicopter; its main characteristics are listed below:

Power plant: One 1342 Kw (1800 shp) Pratt & Whitney Canada PT6T-3B Turbo Twin Pac (single engine ratings 764 Kw; 1025 shp for 2½ mins and 723 Kw, 970 shp for 30 mins).

Main dimensions:

Overall length (1)	15 - 17.1 m	49.21 - 56.10 ft
Overall width (1)	9.9 - 14 m	32.48 - 45.93 ft
Maximum height	4.6 m	15.09 ft
Landing gear track	2.8 m	9.18 ft
Main rotor diameter	14 m	46 ft
Tail rotor diameter	2.6 m	8.53 ft
Weights:	5398 Kg	11900 lbs

Useful load	2463 Kg	5430 lbs
Empty weight	2935 Kg	6470 lbs
External load	2041 Kg	4500 lbs
Performance (ISA, SL, 5398 Kg - 11900 lbs MGW)		
Vne (1524 m - 5000 ft)	260 Km/h	140 kts
Max cruising speed	224 Km/h	121 kts
Climb rate	7.46 m/s	1470 ft/min
Hovering IGE	2804 m	9200 ft
Hovering OGE		
(4990 Kg - 11000 lbs)	2347 m	7700 ft
Service ceiling	4816 m	15800 ft
Max range (2)	675 Km	364 nm
Max endurance (2)	3.6 hours	
Operating conditions:	-40°C to +52°C	(-40°F to +126°F)

(1) Depending on main rotor position
(2) No reserve, 610 m (2000 ft)

The operative restrictions the aircraft is subjected to are minimal, thanks to the fact that the cruising speed was reduced by only 11 knots compared to level flight cruising. The helicopter may also travel with all doors fully closed for the benefit and comfort of the operators. The assembly on board the helicopter is made simple by making use of the links normally provided on the passenger cabin floor; this feature enables the equipment to be easily moved from one AB 412 SP to another.

5. NEW SURVEY PROCEDURE BASED ON CURVILINEAR MEASUREMENTS

5.1 Setting up

A number of chain of suitable type and length are selected according to the centre-to-centre distance of the pipes to be measured.
Each chain bears two indexed targets, close to its ends, which must be clearly visible in photographs taken from a nominal distance of 50 meters. The length between the two indexes at the end of each chain is accurately measured in the workshop to an approximation of ± 1 mm.
The chains are then simply hung from the top of the pipes, festoon-like, making sure that the lowest part of the chain is well above the surface of the sea.

5.2 Photographic recording

Two photogrammetric cameras of which the C.F.L., residual distortion curves and the 'repere' constant are known, are electrically connected so as to ensure excellent synchronization. Special devices allow remote control and checking of the functions.
The cameras are installed on a helicopter at an appropriate (gauged) distance, Bx, which will ensure the definition of a third coordinate ("depth perspective") with the accuracy specified for survey techniques.

The photographs are recorded in the usual way (along vertical, horizontal and tilted axes), but with very short exposure times and using top quality roll film.

5.3 Orientation and restitution

Inner orientation takes place according to the usual well-known procedures.

Relative orientation takes place by means of the elimination through progressive approximations of the vertical parallax, Py, on stereoscopic points distributed over the entire overlap surface and located both on still objects (eg. the pipes) and moving objects (eg. hanging cables, buoys, etc.),and also on the liquid surface visible in 3D.

According to the restitution instrument available, and to the geometric conditions of the orientation taken, one can choose the more appropriate empirical procedure (Von Gruber with Visio or Baeschlin variations, or even the Zeller mine point procedure for tilted phototakes, with or without a visible horizon). Otherwise one can record the Py parallaxes and analytically process them with suitable software. If one has analytical restitution equipment with software for landscape stereo-plotting the problem is solved from the start.

Dimensioning is performed on the 3D images of each chain by comparing its real length, work-shop measured, against the relative scaled down curve length measured on the image.
This operation is conducted in the easiest possible way, that is in the way peculiar to photogrammetry which involves breaking down the chain curve into a number of tiny, practically rectilinear segments, whose overall length is then progressively built up.
The length of the images curve is given by the formula:

$$\overset{\frown}{AB} = \Sigma\ (\ \mathrm{Delta}_{xi}{}^{2} + \mathrm{Delta}_{yi}{}^{2} + \mathrm{Delta}_{zi}{}^{2}\ )^{2}$$

The definition of the scale is given by applying the golden formula of stereo photogrammetry, that is:

$$\text{Image scale} = \frac{\overset{\frown}{AB}}{\overline{AB}} \qquad (\text{mm})$$

N.B.: The length AB remains the same because the chain slack is considered irrelevant.

One should bear in mind that when the base B can be measured within an accuracy of ± 1 mm, the value of Bx becomes a known and fixed element (it varies only when By, Bz components are interested).
In this case an imperfect dimensioning may spring from small errors of convergence between the camera axes which should be adjusted by suitable changing Phi_{left} and Phi_{right}.

Absolute orientation takes place by rotating the model until the mean sea level is horizontal by means of the usual Omega Gen. and Phil Gen corrections.
The following formula is applied:

$$Qo = \left(\frac{\Sigma nla + \Sigma nlb}{n} \right) / N$$

where:

N = number of survey zones, generally 9, located respectively in the couple centre and in the 8 conventional perimetrical locations.
n = number of constant and even reading.
la= altitude reading at wave crest.
lb= altitude reading in wave gully.

Stereo-plotting of the industrial kind, is performed digitally with further data processing by means of specialized software and CAD.

5.4 Advantages of the new procedure

It is obvious that with the new procedure there is no longer any need for the trig point network. The abolition of these points means avoiding both pre-targeting and microgeodetic measurements, thus realizing substantial time and cost saving (in addition to risk of injuries when operating in a hostile environment).
In fact, the only operation in which man remains irreplaceable for the survey is in hanging the special chains; an operation that can be handle by persons who are not expert in topographic surveys but are so in off-shore operations (eg. seamen).
The availability of expert seamen makes the chain slinging operation rather easy and fast.
The only thing left to be checked is which type of chain responds best to practical needs; at present tests are being conducted on the behavioral and handling characteristics of the "Genova", "Galle", and "Landchain" types.

6. APPLICATION FIELDS OF THE HELIBORNE S.E.R. EQUIPMENT

6.1 The virtues of the new improved method for stereo photogrammetric off-shore surveys

It is quite obvious that the solution described turned out to be a complex and costly one to realize. It was justified only by the exceptional needs claimed by off-shore petroleum engineering.
However, the cost and time saving aspects, the reduction of risk to the operators, and the flexibility of surveys which were previously practically unthinkable, amply reward the effort withstood thus making the system economically worthwhile even for the simplest of measurements in an off-shore environment.

Having proved the accuracy of the three-point method it is also clear that its convenience increases with the number of data to be gathered in the survey. For example, irregularities in the circumference, in the thickness of the mouths, or in the cut plane, and also the presence of dents and the accuracy of the vertical standing of the three pipes can be rapidly and economically checked. Moreover the method will prove all the more convenient when there are more pipes.

The use of a helicopter enables full coverage of the survey subject with convergent shooting from various directions. The interlinking of the stereograms which make up the survey, which we might define as "polyhedral", is now possible, and is made easier and faster by the use of dedicated software such as ORIENT, CRABS, etc.

We all know to what extent the introduction of helicopters was a revolution in the working lives of topographers and mining prospectors. It is no gamble to claim that this same means, equipped, with the S.E.R., will have an even greater impact on engineering survey operators thanks to its freely pivoting support.

6.2 Possible applications

In the typical case of an off-shore cluster the general conditions of the pipes can be determined, in other words irregularities in the following aspects:
- alignment;
- parallelism;
- perpendicularity;
- general bearing plane.

Thus, when the survey has been completed, one can check whether the pipe cluster as a whole falls within the dimensional tolerance limits, or only in some of its single components.

Moreover, this method seems to be only one which allows the measurement of floating structures (where the main

subject, complementary parts, and the sea itself each move with individual characteristics and different linear and angular parameters).
Therefore the immediate survey of the damage on ships which have had a collision becomes feasible. The same can be said for the real deformations suffered by petroleum platforms during open sea launching; nowadays these are only found through theoretic calculations.

Finally the method was found to be particularly useful in the "as-built" survey of complex industrial plants, installed on the off-shore petroleum production platform, one after the other, in the so called "wafer" system of construction.
Also in on-shore surveys, the heliborne S.E.R. will supply valuable performance, especially in architectural measurements, geo-technical surveys and within the scope of all 1:20 to 1:100 scale surveys. A few examples:

- recently terminated skyscrapers or towers (in the case of as-built zero surveys used in further checks for sagging and deformation);
- monuments towering above densely built up historical centres;
- complex and difficultly accessible constructions;
- rocky and steep coastal areas on which constructions have been erected;
- serious damaged building which are dangerous to move in;
- rapidly evolving natural phenomena;.
- special applications in civil protection.

7. ACKNOWLEDGEMENTS

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The authors wish to express their gratitude and appreciation to their AGIP and CAPRONI VIZZOLA colleagues for their collaboration: respectively for the feasibility studies of the new photogrammetric method and for the complete realization of the Heliborne Pivoting Support (SER).
Thanks also to the technicians of the COSTRUZIONI AERONAUTICHE GIOVANNI AGUSTA for the collaboration supplied, and namely to Mr. Carlo Ferrarin, engineer, who was responsible for coordinating the construction and applying some of the more significant project solution.

8. NOTE

The S.E.R. was certified by Registro Aeronautico Italiano as a kit installation for the AB 412 Agusta helicopter the 27 June 1988.

The full operability of the system was shown during a measurement campaign conducted by AGIP near Ravenna on July, 15.

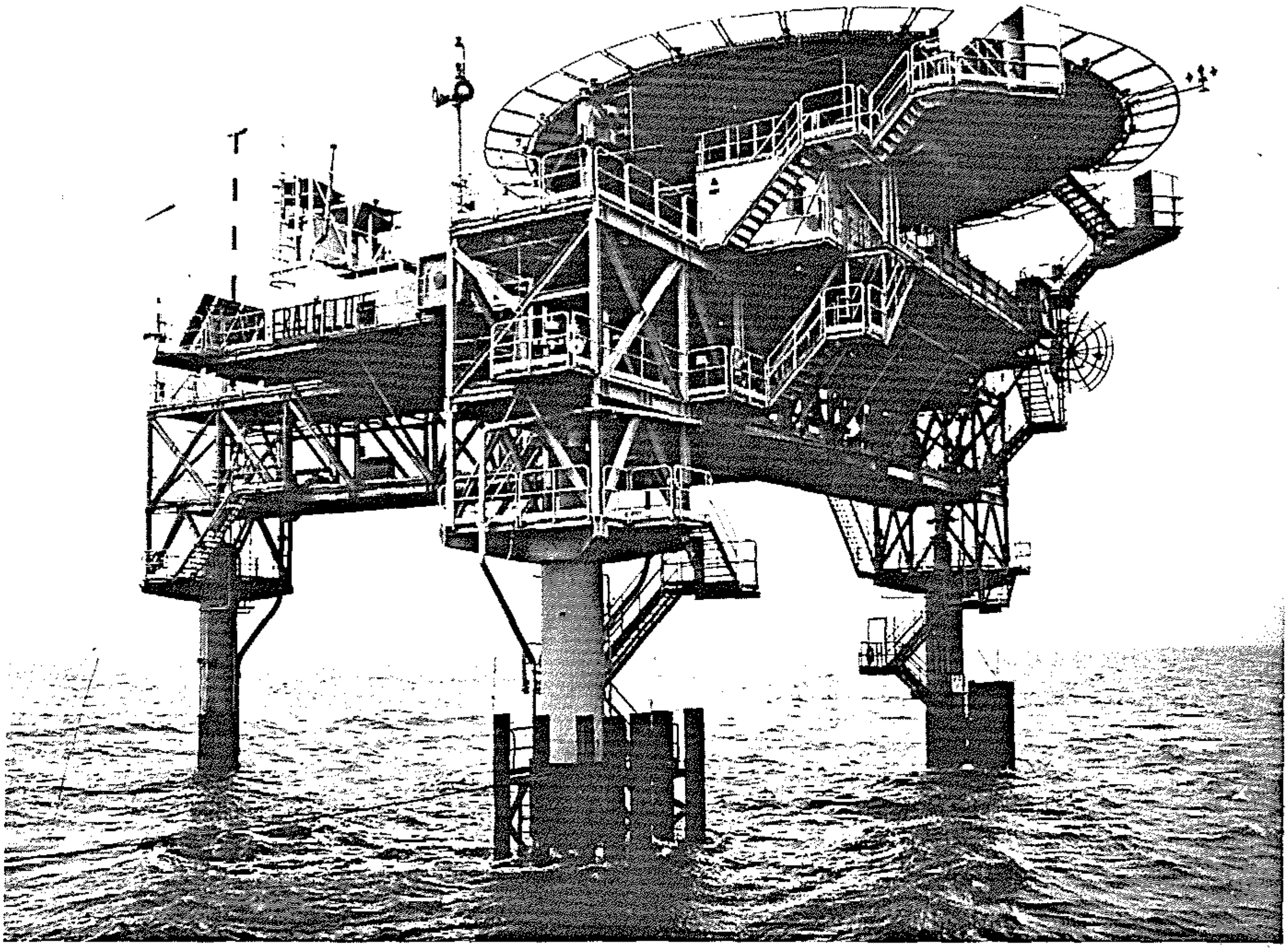
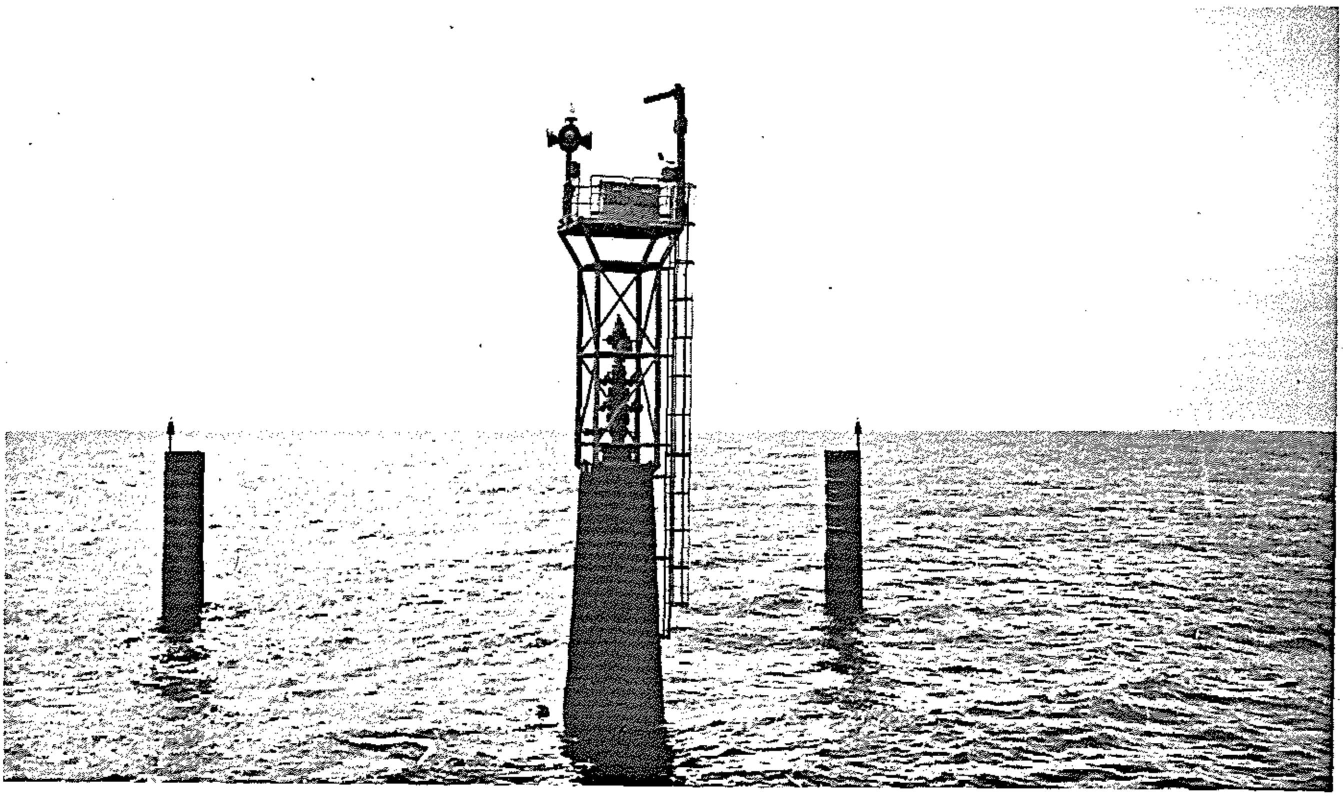
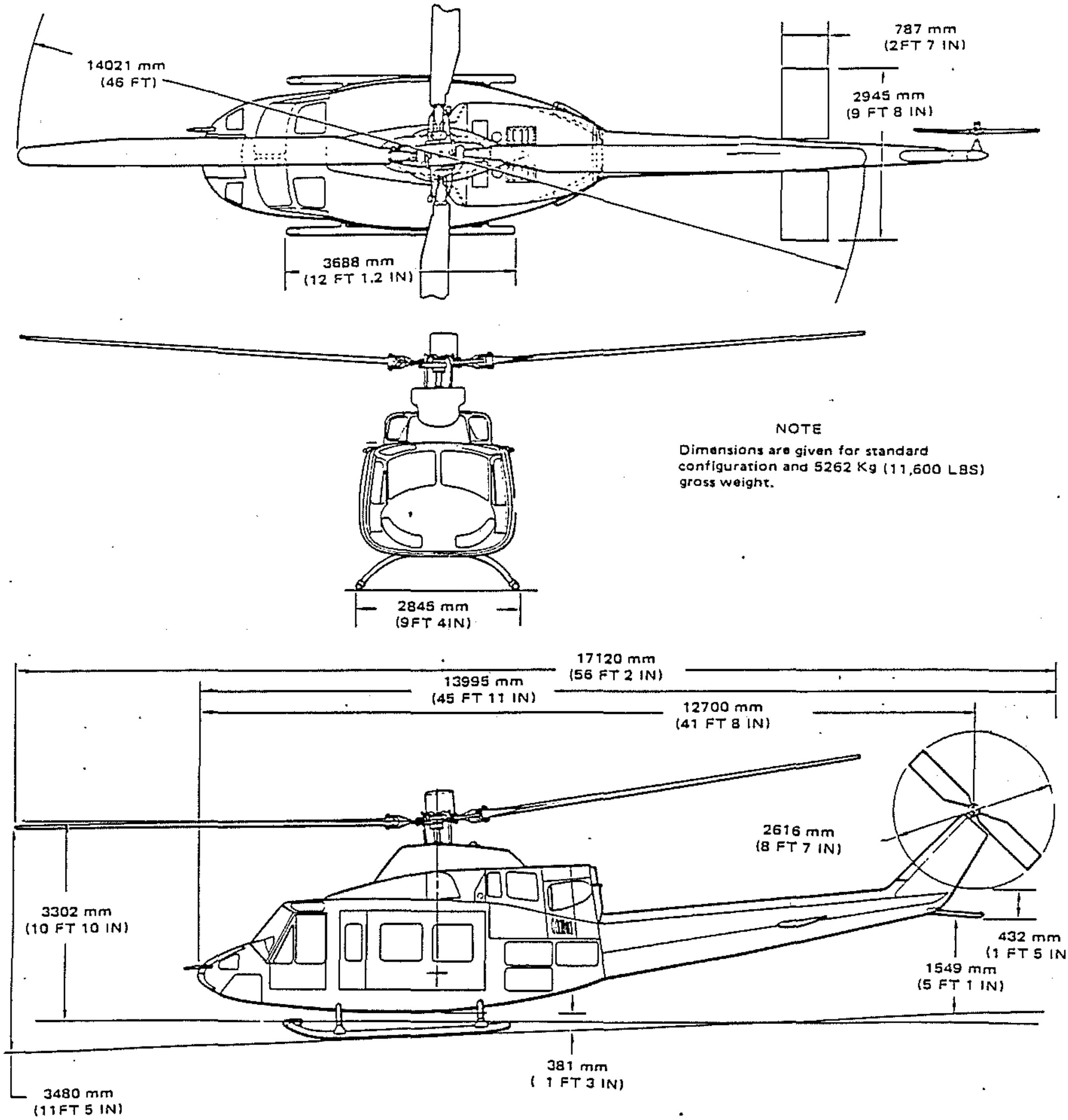


FIG.1 △

▽ FIG.2





AB 412 SP

Helicopter principal dimensions.

FIG.3

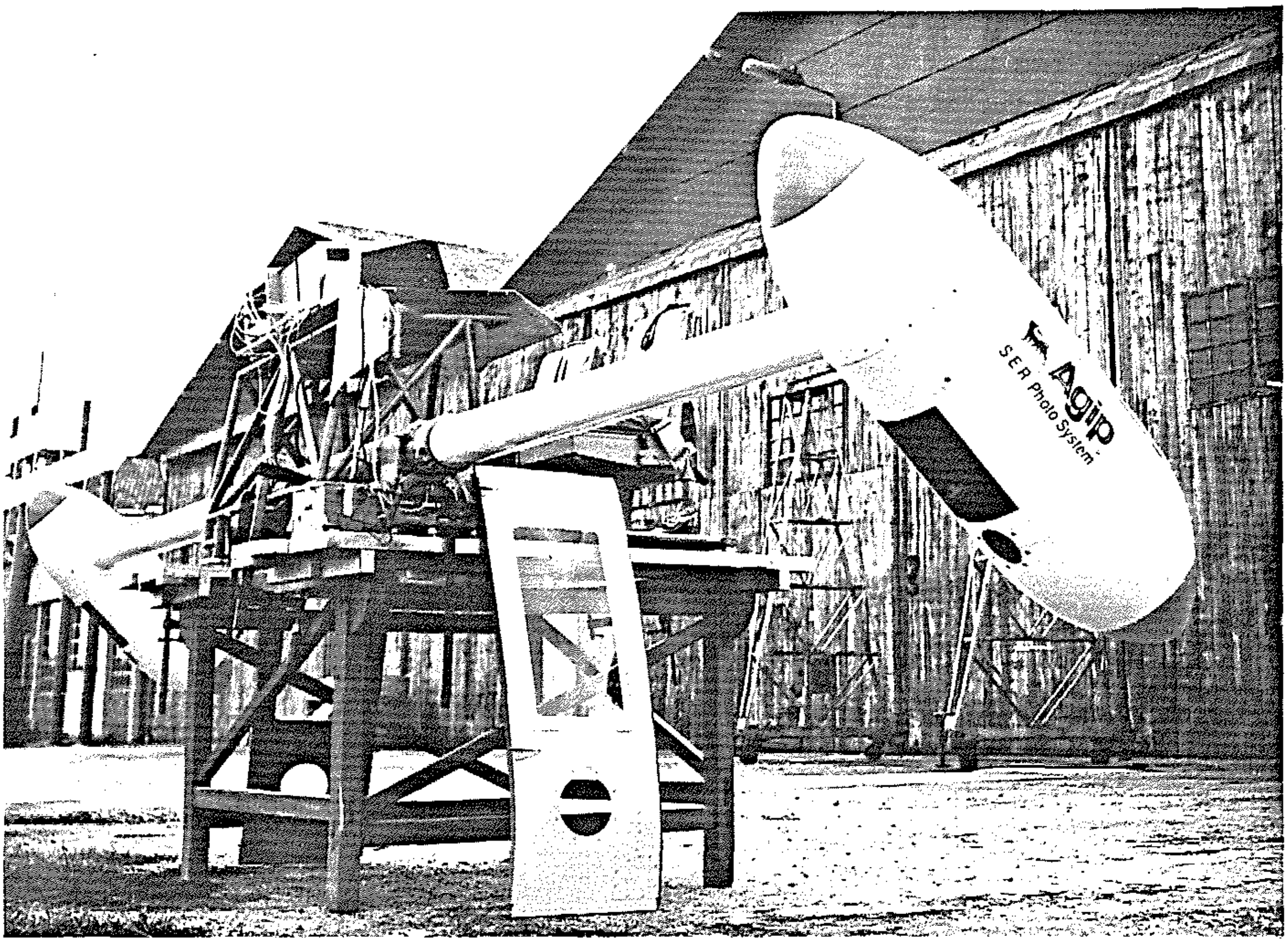

Agip
S E R Photo System

FIG.4

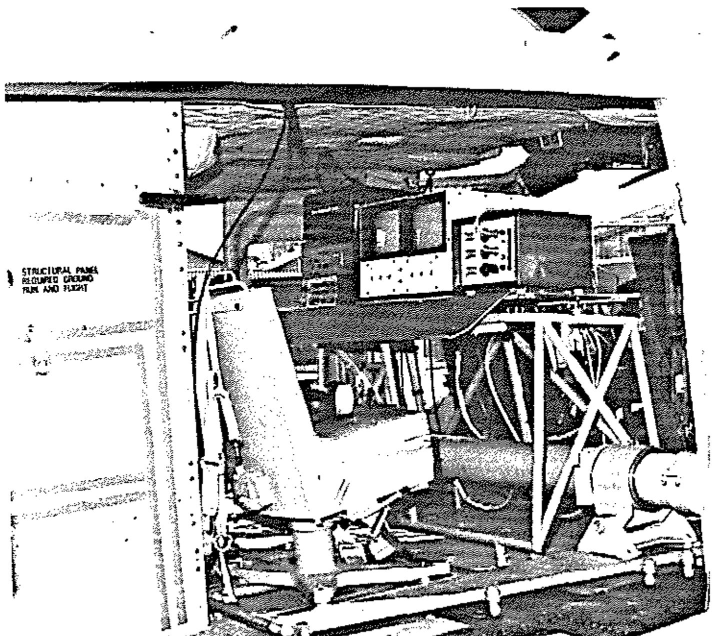
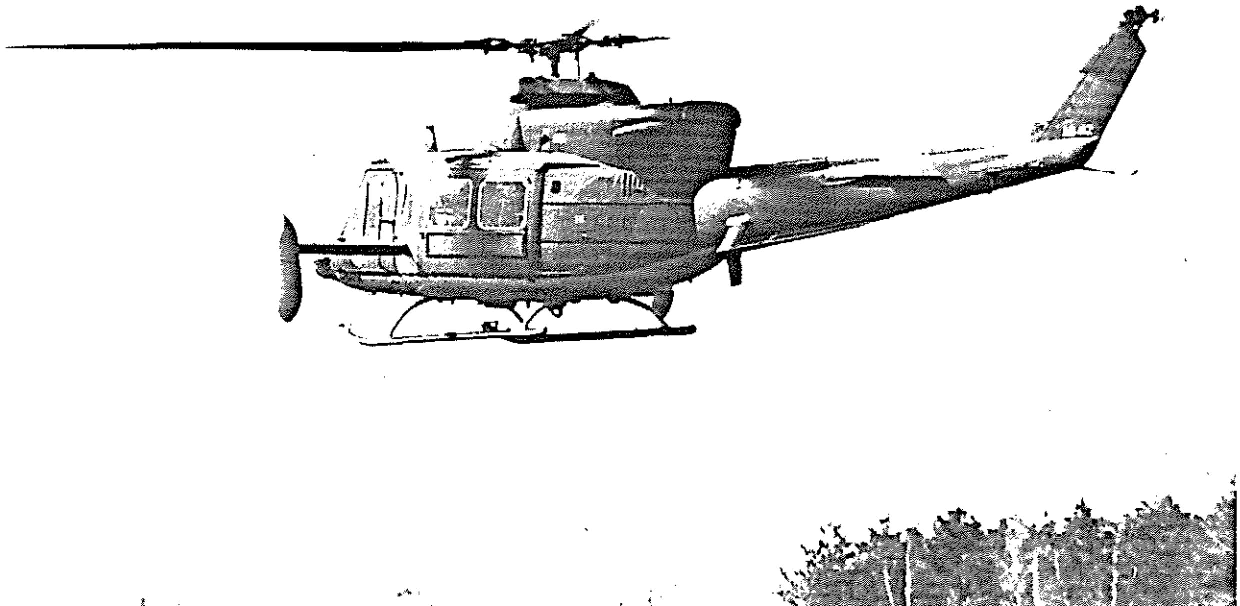

STRUCTURAL PANEL
REQUIRED GROUND
RUN AND FLIGHT

FIG.5

FIG.6 △

▽ FIG.7



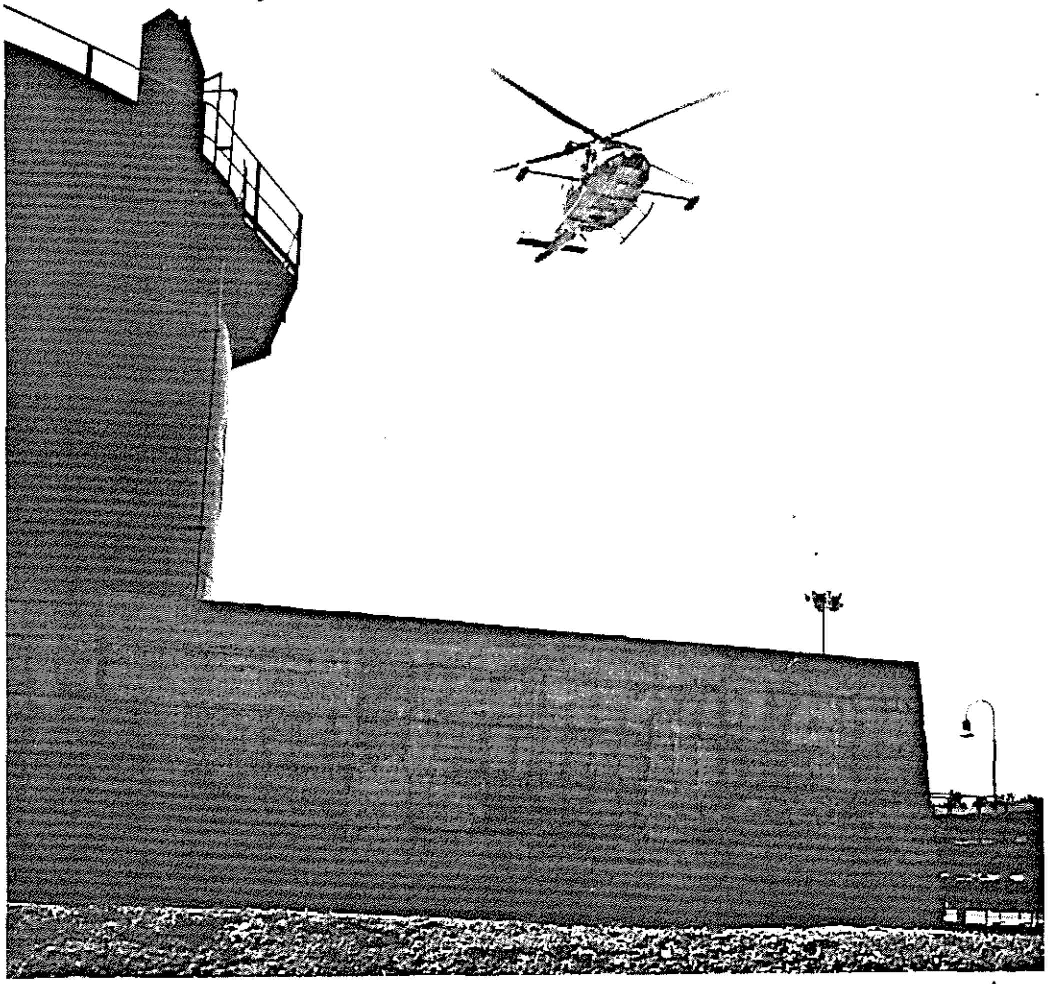


FIG.8 △

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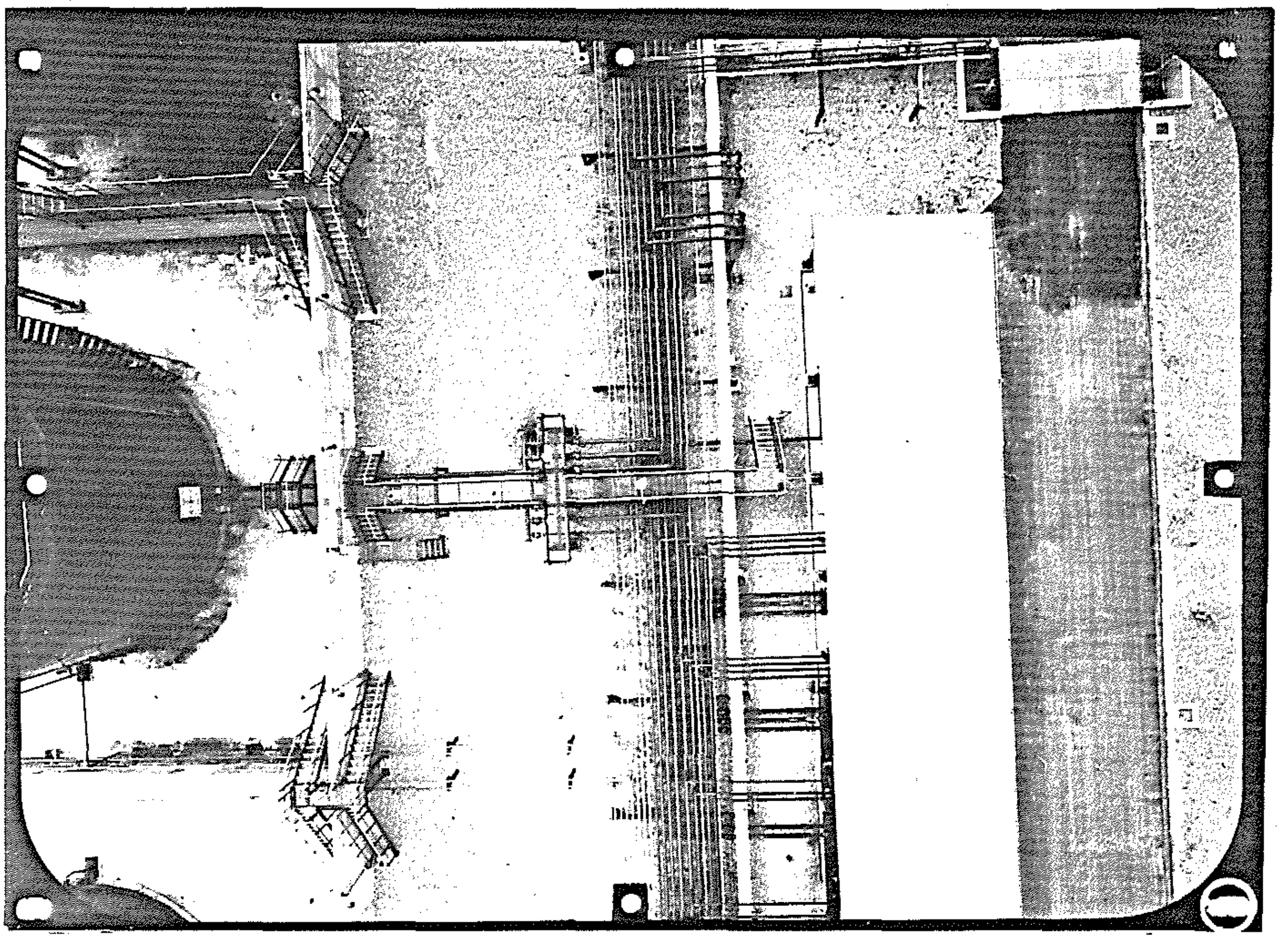
▽ FIG.9



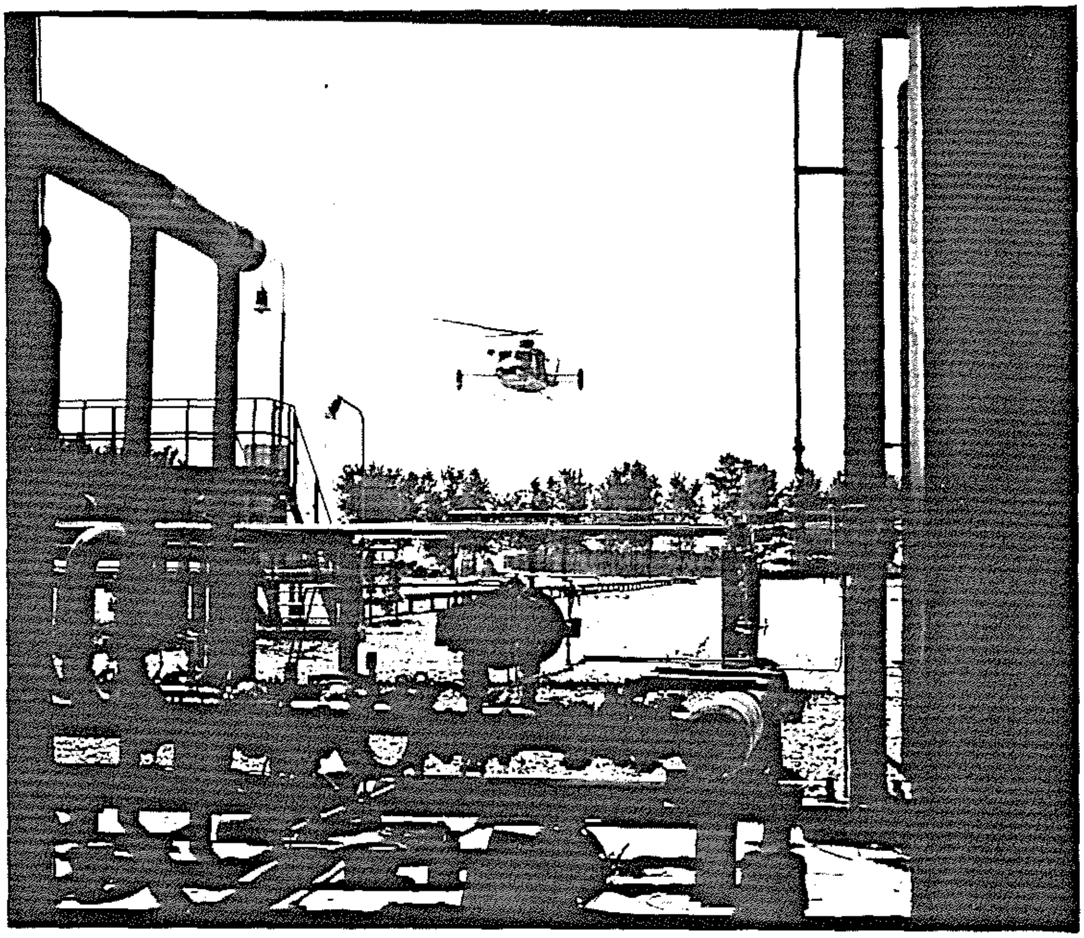


FIG.10 △

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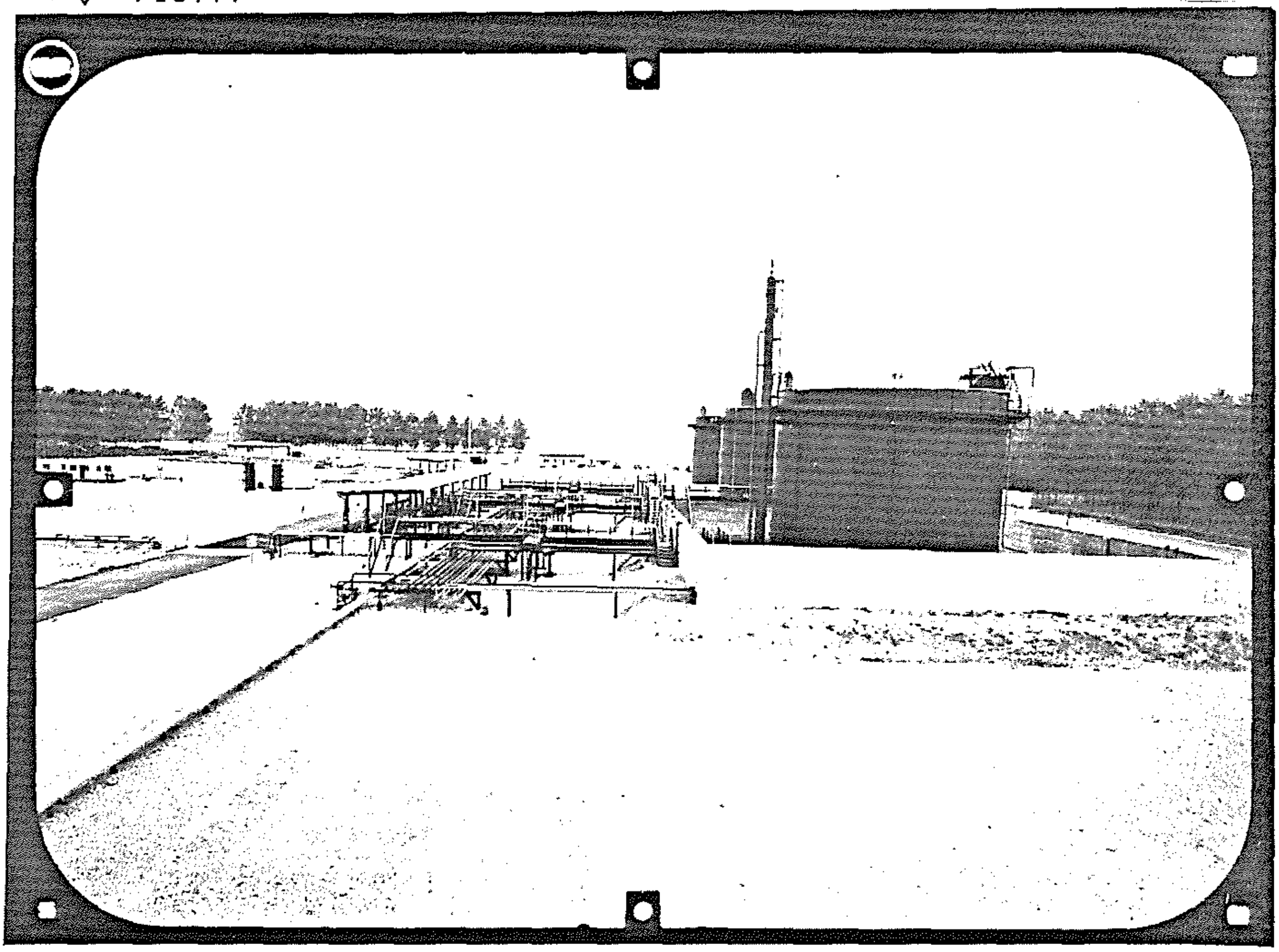
▽ FIG.11



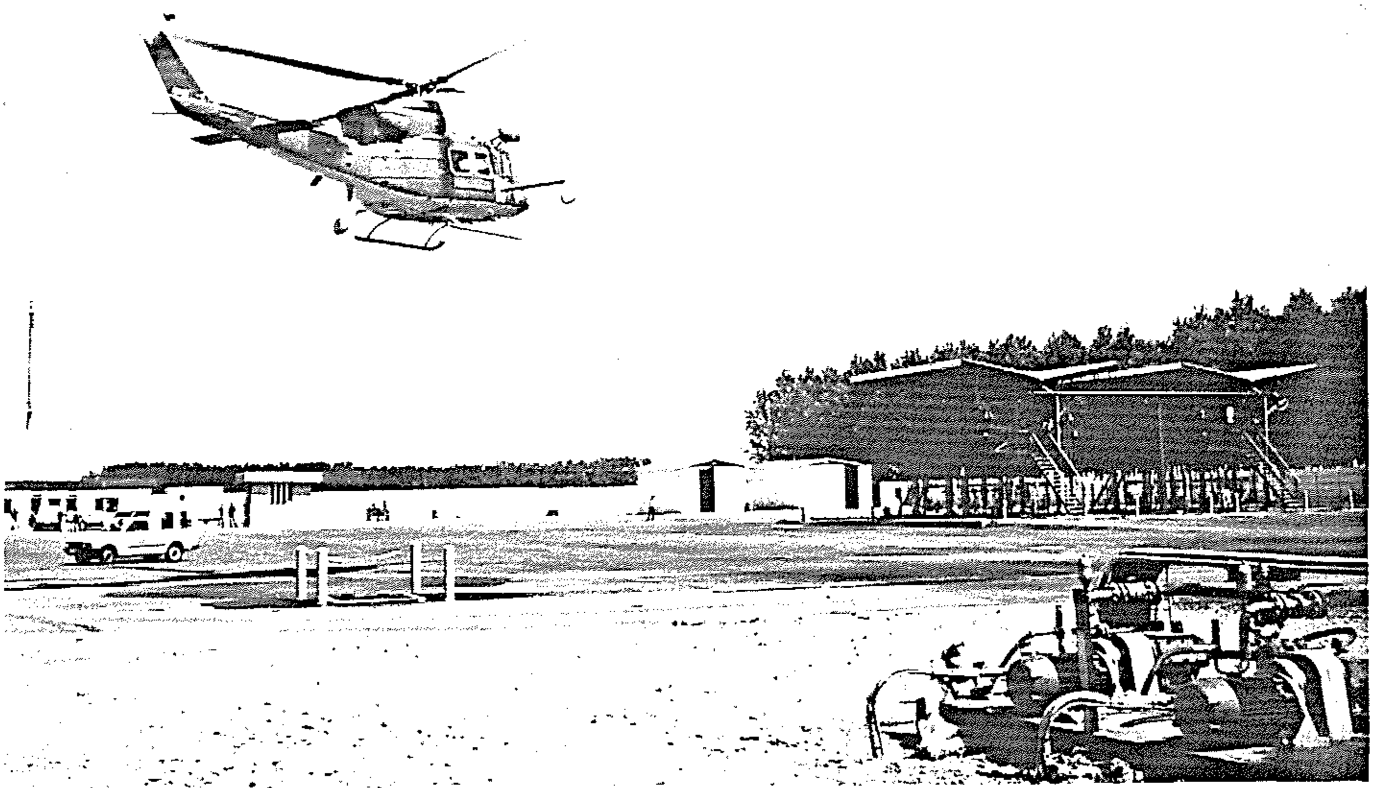


FIG.12 △

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▽ FIG.13