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## P.I. INSTRUCTION MATERIALS

(THESE TEXTS ARE ON HAND IN 30-40 COPIES)

VOL II

(See Vol.I for photos)

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In addition to photos and texts indexed here,
D/GP has on hand 40 - 50 copies of the
Photo Interpretation Handbook and
Photo Industrial Studies 1 thru 9.

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D/CP - BASIC COURSE IN THE USE OF AERIAL PHOTOGRAPHY
FOR INTELLIGENCE PURPOSES

A. Definitions:

1) Photo Intelligence is the blending of all other types of intelligence with photographically derived data. It may confirm, deny, supplement or, where no other information exists, stand alone. It presupposes general intelligence competence; its raw source - photography - is A-1.

2) Photo Interpretation and Photogrammetry are methods for deriving information from photographs. Photo interpretation aims to tell the meaning, including the relationships and functions, of what is seen in photographs. Photogrammetry is concerned with obtaining reliable measurements by means of photography and reaches its most extensive use in mapping. Both employ each other's skills to some extent. Photo interpreters make normally simple measurements to establish scale and identification, and photogrammetrists employ recognition techniques required for object identification.

3) Photo Reading is a basic skill comparable to learning an alphabet, enabling the student to orient photographs upon a map, to use a stereoscope, and to recognize the photographic appearance of familiar objects. In practice, for CIA purposes, this involves also photo procurement, i.e., knowledge of various special bodies and sources of photography.

B. Division of the Field:

1) Photo intelligence is empirically divided into two major fields:

a) Geographic - Focused on natural features of the earth and their relationship to the uses of man.

b) Industrial - Focused on the detailed interpretation of man-made structures.

2) These are in turn divided into specialties, which have arisen in part through the historical growth of photo intelligence in response to the wartime requirements of the various components of the Armed Forces. Main specialties are:

a) Air - Airfields and aircraft, anti-air defenses, target charts, sometimes A/C manufacture, and certain AF targets.

b) Navy - Naval and merchant shipping, ports and harbors, marine mapping, coastal defenses, shipbuilding and certain Naval targets.

[redacted]

c) Army - Ground force materiel installations and fortifications. Tactical and strategic terrain analysis, sometimes AFV, weapons or ammo manufacture, certain AF targets.

d) Industrial - (proper) Industries, power and raw material supplies. Certain forms of transportation.

e) Communications & Signals - Radar - radio installations. Sometimes a separate field.

f) Atomic Energy - De facto a separate field due to security clearances required.

g) Vulnerability and Strike Damage - In wartime a highly specialized crash action field; involving mathematics of bomb fall plotting.

h) Geographic Specialties - Arctic, beach analysis, other special areas.

i) Mapping (Tri-met, vertical and oblique) - Military services and civilian.

j) Photo Geology - Civilian, mineral exploration.

k) Radar Scope Interpretation - Involves recognition studies for specific targets.

l) Ultra-Violet & Infra Red - (Thermal emission) radiation record analysis.

m) Miscellaneous - Human recognition, clandestine, medical, etc.

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# HOW TO MEASURE OBJECTS SEEN IN AIR PHOTOGRAPHS

(I.E., HOW TO FIND THE SCALE OF VERTICAL AERIAL PHOTOGRAPHY, WITH A NOTE ON FINDING HEIGHTS)

Warning: Avoid measuring in inches if possible because if you do you will have to divide all your measurements by 12 in order to come out with feet. To avoid this, use the .001' (thousandths of a foot) scale which multiplies out directly into feet, or use the .5 or .1mm scale which will give you metres and kilometres.

METHOD I. If you have a reliable map or controlled mosaic of the area:

A. Measure on the map or mosaic the distance between two points shown on your photo. Choose a line which crosses near the centre of your photo. Multiply your measurement by the scale of the map or mosaic. Example: If the map's scale is 1:36,000 and you measure .2' between points, the actual ground distance is .2 times 36,000 or 7200 feet. (Watch the decimal!)

B. Next measure same distance on your photo and divide it into actual ground distance. Example: Suppose the distance between the two points is .431' on the photo. Divide this into 7200'. The scale of the photo is 1:16,705, also written 1/16,705. Now you can find the actual size of any object on this photo by measuring it and multiplying by 16,705.

General rule: Ground distance divided by photo distance gives you the denominator of the representative fraction which is your scale.

Watch those decimal points

METHOD II. If you have the focal length of the camera and the altitude of the plane:

Scale is found directly by dividing altitude by focal length. Be sure to turn inches into feet before dividing. Examples:

24" FL at 30,000' Alt : 30,000/2 = 15,000. Scale is 1:15,000

6" FL at 30,000' Alt : 30,000/.5 = 60,000. Scale is 1/60,000. (Very small)

(More examples)

6" FL at 7,500' Alt. is also 1:15,000, the same as 24" FL at 30,000'.

12" FL at 10,000' is of course 1/10,000.

Note: On USAF reconn photography, the altitude is usually written on the first and last prints of the mission, and sometimes on others. Focal length is usually on the margin of all prints. However, since the plane may not fly a dead level line, and the terrain may rise or dip, this general scale may give only an approximation which should be checked for accuracy on individual prints.

German Air Force photography always shows the camera's focal length in cm in a corner box on each print (the lowest figure) but do not give altitude. Hence scale must be found by Method II or III or both.

METHOD III. <u>If you do not have an accurate map and do not know focal length and altitude:</u>

A. Find some distance or object on the photography the size of which you know accurately. (If all else fails, guess.) For example, it is often possible to get exact figures on airfield runways, wing span of planes, lengths of railroad cars, track gauge (where visible), length of bridges, parks or monuments, sports' fields or stadia, dams, distance between radio masts, ship or barge lengths, gas tanks or gasometers, armored vehicles, trucks, (width is more reliable than length unless you are sure of model) or even large animals on large scale cover.

B. Using these estimated or actual ground distances, divide by the measured size of the object on the photo. Example: Taking the average length of Russian 4-axle boxcars as 15 metres, and two-axle cars as approximately 8m, suppose they measure 1.5 mm (0.15 cm) and .85 mm (0.085 cm) respectively on the photo. The scale will be between 1/10,000 and 1/9,412. The discrepancy is primarily due to the fact that there are many types of USSR cars, and it is not possible to determine exactly which type you are seeing at this reduction. To reduce the margin of error, make as many and as accurate measurements as possible and take the average. It may also be possible to search adjacent photos or other photo missions over the same area for large known objects such as airstrips or canal locks and transfer the scale back to your photo, print by print. (Example: The Chapayevsk Explosives Plant #15 - 309 is covered in large scale photos. There is small scale cover of the plant and neighboring airstrip. A tentative scale was taken from freight cars visible in the large scale cover, and used to establish size of a large building also visible on the small scale prints. This gave the scale for the small scale cover, which was then used to measure the airstrip on this print. The measurement came out within 10% of the size reported in contemporary German target data, thus confirming the first scale found for the large-scale cover of the plant within a very small margin of error.

Note: The larger the scale, the larger the images of the objects shown, but the smaller the denominator figure in the scale. 1:1,000 is a very large scale, 1:100,000 is an extremely small scale. At 1:5000 you can see human beings; they will be about .0004" across in vertical view. At 1:50,000 this same measurement would be a 20-foot diameter, on the ground. (Barely visible.) A large factory is hard to spot at this scale.

Warning about accuracy of scale: You will never get an entirely accurate scale except by chance. Where accuracy is important, keep working at successive approximations and cross checking. When using Method I and working from a map or mosaic, make at least one additional measurement at right angles to the first, across centre of photo, and work out a second scale. It will differ slightly from the first. The difference between the two scales is your margin of error, expressed as a percentage. It may run as high as 15 or 20%. 5 to 10% is usually tolerable, in fact almost inevitable.

The longer the distances you use to establish scale, the more accurate you will probably be.

The more measurements you work, the greater your accuracy.

When measuring, remember white objects show slightly larger than they are, because a light area will "halate" into the darker area adjoining. Avoid measuring extreme shadows or light areas.

Be careful not to include the shadow of a building when measuring. If measuring from the eaves' edge on one side of a roof, use the same edge on the other side. When the picture is tilted, you may get part of the wall on one side and lose part of the roof on the other.

Remember: A photograph is not a map --- it is only vertical at the centre.

No map is perfectly accurate.

No measurement is perfectly accurate.

No photograph is perfectly accurate.

(But it is still an A-1 source.)

See next page for remarks on tilted photos and finding height.

## TILT

When the photograph is visibly somewhat tilted and buildings are seen in partial oblique, the scale becomes increasingly distorted. Use ground measurements and avoid measuring in the direction of view (i.e., toward where the horizon would be if tilt increased.) You will find that measurements taken across the direction of view near the centre of the photograph will be fairly harmonious. A square building will measure shorter than it is in the direction of view due to foreshortening. A scale obtained from such tilted photographs is useful only for rough approximations. Many photos are slightly tilted. To determine how much, inspect tall objects, buildings or stacks, at the centre of the photo. All photos show a "tilt" or oblique effect increasing toward the edge. A photograph over a field of straight vertical poles, or soldiers in formation, will show them apparently leaning outward from the center.
For obliques over 5° from vertical, complex methods are used.

## HEIGHT

There are three methods to find the vertical height of objects or hills. In all, the scale must first be found. After finding the scale, you may proceed by following the directions in the Photographic Interpretation Handbook. In the accurate "parallax method" two overlapping photographs and considerable mathematic accuracy is required. Good results are also obtained by the two "shadow factor" methods. For one of these you must know the date, hour & minute of photography, for the other you must know true North. The German photographs often give you exact time on the camera clock shown in the print, but the clock was set at the squadron base. Hence the true North or azimuth-shadow factor method is often the best method to try first. This is done easily by the aid of the tables in the Handbook.

Note: In both shadow factor methods the coordinates of the area photographed must also be known.

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# HOW TO RECOGNIZE AND ANALYZE INDUSTRY FROM AIR PHOTOGRAPHS

## Introduction:

This manual is intended for use by intelligence officers with no previous training in photo interpretation. It gives a twelve-step method for analysing industrial installations shown on air photographs. By this method, users will find it possible to recognize plants in which they are interested and to confirm or deny certain ground reports. It will be found that the experience of intelligent seeing always adds to knowledge.

This manual will not make the user into an industrial interpreter. Industrial interpretation proper requires elaborate measurements and study of visible factors affecting capacity. Those users who are industrial experts already have the technical knowledge to become superior interpreters if they wish to go on with the study. This manual will enable them to bring part of that knowledge to bear and determine how much farther they wish to go in exploitation of the visual record.

Note: Although this manual is directed toward air photography, much of the material will be found helpful in dealing with ground photographs.

## General Principles

Industrial interpretation is a three-way process of evaluating general principles against the concrete visible facts, and using both against ground reports.

The general principles of industrial interpretation are the knowledge of the patterns of plant layout, the flow of materials from process to process, and the requirements for power, transport and other utilities.

Certain major industries and industrial complexes have typical patterns which can be recognized on air photography almost at a glance. Among these are:

- Hydro-Electric Power Stations
- Thermo-Electric Power Stations
- Coke, Iron and Steel Plants
- Rolling Mills and Heavy Assembly
- Alumina-Aluminum Plants
- A/C and A/C Engine Plants
- Shipyards
- Submarine Pens
- Mines and Quarries
- Cement Plants
- Railroad Yards and Shops
- Producer or Coal Gas Plants
- Coke Oven By-Product Plants
- Oil Fields
- Petroleum Refineries
- Synthetic Oil Plants (some)
- Nitrogen Fixation Plants (some)
- Explosives Factories (large)
- Pulp and Paper Plants
- Brickyards
- Grain Silos and Mills
- Sulfuric Acid Plants (some)

The interpretation of most of these industries has been explained in detail in Photo Industrial Studies 1 through 9, obtainable thru D/GP. A few general examples are shown in the Photo Interpretation Handbook, and there are also certain reports and manuals to help you in a specialized study. The supplement to this manual will include a basic text and some examples of these "standard" industries.

However, it is worth noting that the patterns of even these industries vary from country to country depending on the amount of available land, the date of construction, the state of the technology, the raw materials used, and the type of transport or labor. U.S. plants using the same principles and processes often appear superficially very different from those of Asia or Europe.

In addition to these most easily recognizable industries, there is a host of other industries which can only analysed in a general way from air photographs alone. These include miscellaneous engineering and assembly plants, "light" industries such as textile mills, and a great many chemical process plants. Here a big part is played by reasoning, deduction, knowledge of the area, and above all, careful observation. One must look closely for significant features which can be used to tie down the analysis in combination with ground report.

Visible Facts and Ground Reports

The concrete visible facts are of course those things which are seen on the photograph. It is very common to see, say, six buildings where ground report says there were two. Four stacks, or none, will be found where ground report says there was one. What is seen cannot be doubted; it existed. One must develope something of the talents of an amateur psychologist to determine what the source was talking about, why he saw it that way and how much to believe. Analysis of ground reports by the light of photographic information, reveals how inaccurate most observations are. Sources who know where a place is may not know what it is, and those who are confused about the outward appearance of a plant sometimes do know the process used.

Procedure:

To analyse industry from air photographs, work carefully through the twelve points listed below. Cover each one; even though you feel you know your industry almost at once, you may have to revise your judgement at the very end. Sometimes you will get important clues from the things you cannot find---for example, the absence of labor housing, or a lack of heavy handling equipment. Where you are puzzled, simply note what you can see.

The questions to answer under each point are discussed in detail in the pages following. After each object or appearance named is a number which refers to an illustration of that object in the supplement. Some of these illustrations will be issued along with this text; the remainder will be forwarded to holders of this manual as soon as available, for incorporation in a permanent looseleaf binder.

The object of the illustrations is to make sure you have a clear mental picture of at least one example of the object, in vertical view. This is only a bare minimum. If you wish to develope your recognition ability, keep looking closely at all kinds of photography* and at the world around you. For instance, do you know what ice in a river looks like? Have you observed how foot-paths indicate ground contour? Can you form a good idea of how your home looks from the air?

*There is an excellent JIB Guide to Reporting on Industrial Installations for ground observers. (JIB 1/6, Aug'50, and Supplement.)

Do not be discouraged at the apparent length of the procedure. The discussion below covers almost all possible variations. After a few trials you will find it becomes automatic to run over a quick mental check list.

You may feel it is unnecessary to look at things in which you are not directly interested. Why should an oil expert learn to recognize an alumina plant? The answer is that he must develop a broad recognition ability in order to avoid mistakes. The analyst who is interested only in, say, coke-ovens, will see coke-ovens in places where they do not exist, because he does not know how many other things look something like a coke-oven.

Beware of snap judgements: Each plant is an individual entity. None of them confirm completely to pattern. Some industries "mimic" others---for example, cement and soda ash. Certain key structures can be overlooked or mistaken for others at small scales---e.g., smelters for distillation towers. Plants may have been converted to other uses with scarcely a visible trace. Certain industries are completely uninterpretable without ground data. Specialty plants making such things as insecticides or X-ray equipment may resemble well-known types. Finally, non-industrial structures may create confusion---for instance, a roller-coaster under construction.

Remember to look at the shadows. Every shadow means that a solid object was there, even if you cannot see the thing itself. Shadows are at least half of the material of interpretation.

Finally, remember how small are the things you are looking for when seen from ten or twenty thousand feet. A rail spur can be invisible. Buildings appear to merge. The most difficult point in all photo interpretation is negative evidence---to be able to state that something is not there.

Here are the points to cover:

The Twelve-Step Analysis:

1) Orient yourself---location, direction, date, scale

2) Define your plant area

3) Look over all the buildings

4) Pick out stacks, smoke and steam

5) Analyse communications and traffic

6) Identify storage---warehouses, stockpiles, tanks

7) Study the utilities supply

8) Look for certain special recognition features

9) Check for construction, destruction, operational status

10) Note security and defenses

11) Locate the labor supply

12) Make sure there are no surprise factors in the vicinity

Point 1) Orienting Yourself:

Where is the place on the map? Which way is north? Where do the roads lead to? If there is a river, which way does it run?

What sort of area is it? Urban (1) or suburban(2)? Farmland (3)? Forested (4)? Heavy industrial plants (5) or light industries (6)? Warehousing (7)? Rail junctions (8) and trans-shipment (9)? A military area (10)?

What is the terrain like? Rugged (11)? Sandy (12)? Swampy (13)? Where is the highest ground? Was this area fought over or occupied?

25X1X7

What is the date? What time of day is it? Look in the margin for the date: On U.S. [redacted] recon. photos the date will be on each print; the hour only on the first and last prints of the mission; the clock face on German photography usually notes the day and month and sometimes the year (14). (Initials seen there are those of the observer.) The clock should give you the time, and will indicate the sequence of photos in a series. Check the date by observation; is it winter (15), summer (16), spring (17), or fall (18)? Judging by the shadows, what time of day is it (19)? Make a careful note of shadow direction, so you can tell faint shadows of pylons and stacks from ground marks. Note also any blurring or blobs from photographic develepement (20). Thumbprints and drops have been interpreted as ground markings.

Get a mental idea of the scale. What is the ground distance from side to side of the photograph? Look for trucks and freight cars to give you an idea of the size of buildings (21). You do not need exact scale at this point; but you should be able to sort out the buildings over 100 feet long. When you decide to determine the exact scale, use the D/GP simplified instructions for finding scale (included in supplement) or the formula in the Photo Interpretation Handbook. You will probably need an Air Target Mosaic of the area or an accurate large-scale map. The annotated Air Target Mosaics (25 MA Series) will also help you identify other installations in the area. Be sure to note the date of issue; some of the information may have been superceded.

Check the photograph for tilt. Is it a true vertical or do buildings appear in oblique view at one edge (22)? If so, you may have to turn the photograph around to find a more natural image. Measurements will also be distorted; see D/GP text on scale. The general rule is to hold vertical photographs with the shadows falling toward you, but you will find it very helpful even with true verticals to turn them around from time to time for a fresh look.

Point 2) Define the Plant Area:

Pick out the plant boundaries and follow them all the way around. Note fences, walls, guard-towers, gates (23), and cleared fire lanes (24) (which may also serve as security clearways). Sometimes a fence will seem to disappear when it runs in the shadow direction (25). Check other photos to see if it is really there. Wire fences can sometimes be seen as thin dark strands; you are seeing the shadow of grass or weeds along the fenceline, not the wire itself (26). Footpaths may reveal the location of wire fences (27). Almost every Russian plant is heavily fenced. Workers will sometimes enter through a guard-building rather than an open gate(28).

Note any fenced-off sub-areas within your plant (29). Sometimes these will contain special processes or research laboratories. They may also be food or other stores, or a box plant.

You may see a formal plat of lawn, perhaps with a statue, in front of the administration offices (30).

Is the plant crowded and jumbled, or open and well-planned (31)? In general, does it look grimy as with coal dust, or white as with construction spoil or lime (32)? Is it clean and new-looking (33)? Have plant boundaries been changed or expanded? Check successive photographs if you have them.

Point 3) Look at the Buildings:

Pick out all the large buildings---and look at the smaller ones too. Note the roof types: Flat, saw-tooth, monitor, transverse monitor, gable, hip roof, and hangar types or "quonset" roofs (34). Does the construction seem heavy or light (35)? Paying close attention to shadows, pick out the tallest buildings or parts of buildings; elevator shafts, heavy machinery, forges, smelters or chemical towers may be here (36). Where several buildings seemed to be joined together, check the joints closely to see if they really are interconnected; often pipelines or conveyors can be seen at such points (37).

Note roof stains (as distinct from camouflage) and skylights, ventilators, and other structures or openings in roofs (38).

What is the general pattern of the buildings? Can you spot certain types such as warehouses, garages, administration offices, research or drafting shops, personnel quarters, etc., as distinct from process buildings where the factory operations are carried on (39)?

In looking at the process buildings themselves, you may have already spotted such characteristic buildings as forges or foundries, open hearths, aluminum pot-rooms, rolling mills, etc. (See Point 8) Unmistakable as these may seem, continue to analyse the plant before accepting them as confirmed. You may find a second industry in the site, among other things.

Remember that trees can hide substantial structures; check winter photos of the area (40).

Be sure you have given a sharp look at every building. Most of the small ones are probably sheds, miscellaneous stores, repair shops, and so forth---but they aren't as small as they seem and they may give you important clues for orienting ground reports. It is usually such minor structures and sheds that POWs are familiar with.

Check for underground installations, bunkers (41), tunnel entrances (42), etc. You may see cables or pipes going into a conduit (43).

Note: On future photography we may expect to find evidence of underground factories. (See the Air Force Manual 200-35 on underground factories from World War II.) Remember, it is possible to go overboard on the subject of underground installations. Reports of vast secret stores or complete underground factories sometimes turn out to be oil-cans in a quarry shed (44). Building foundations, bunkers for storing vegetables, air-raid shelters, may be seen. Fuel oil tanks are frequently buried, and show as small circular mounds (45. If you suspect large underground diggings, where is the dirt which was dug out (46)?

There are three types of "underground" installations: (1) Normal industrial fire and blast protection of explosive or flammable materials, covered or protected by earth walls (47); (2) Concealment during attack consisting of camouflage or partial mounding to confuse a bombardier; such camouflage usually does not conceal the installation on a photograph (48); (3) True protection from aerial bombardment or complete concealment: This means putting vital processes and equipment completely underground (49). If complete concealment is intended, all escaping fumes and smoke, steam, excavation spoil, traffic entrances, etc. must be hidden. This is very difficult for most industrial operations. Aircraft assembly, of course, may be carried on in a cave; iron smelting, fuming acid processes, hardly. A few hundred workers entering and leaving---not to speak of raw materials and product---will leave conspicuous tracks.

However, if you really think you have an underground installation, consult the Air Force's handbook for recognition features. It is always worthwhile to inspect cliffsides, tunnels, old mines and suspicious appearances in regions known to have natural caves.



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Point 4) Pick out stacks, smoke and steam:

You have already noted many stacks; now make a careful search for all of them. Vents over small engines, kettles or furnaces may show as thin "sticks" or shadows along a roof ridge or joint (50). The shadows of very large stacks sometimes escape notice at first because they are so long or are obscured by smoke (51). Check shadow direction again; sometimes the shadow of a stack may fall exactly along the eaves of a building and be overlooked (52). An earth scar may simulate a stack shadow (53). Where the scale is large, it may be impossible to get stereo on a very tall stack---it will appear crossed (54). Sometimes stacks are invisible, and only the shadow can be seen. Note which stacks are smoking.

Try to distinguish smoke, steam and acid fumes. Steam is always white (55); smoke ranges from white to dark grey (56). Look along the roofs for small jets of escaping steam, such as may be released periodically by a drop-hammer. Acid fumes are very hard to be sure of; orange fumes appear white or black on different film. Fumes in general are somewhat dense or steamy-looking, and often leave a stain on the roofs around (57). The vents from the paint shop in an assembly plant will also be surrounded by stain (58); and any dusty or cindery material whitens roofs (59).

On wartime photos, be sure you are not mistaking incendiary fires for industrial smoke, or vice versa (60). (If in doubt, check the changes on the series of photos.) Bessemer "blow" flames (61), slag and rubbish dump fires (62), waste gas flares, may also be seen. (63). On cold days, open "water", and warm roofs will "steam".

Check the shadows of dense smoke clouds; sometimes these resemble objects (64).

If you see cooling towers, which are emitting wisps of steam (65)? Are there any locomotives or donkey-engines letting off smoke or steam (66)? Is there a general smoky haze over all or part of the plant (67)? Are any stacks water-jacketed, or carrying dust-reclaiming apparatus (68)? Look at the base of stacks set slightly apart from boiler-houses; you may see a small structure housing Cottrell precipitators (69).

Finally, make sure you have not identified power pylons, statues, chemical towers or flagpoles as stacks (70). When in doubt, suspend judgement.

Point 5) Analyze Communications and Traffic:

Your aim here is to answer these four questions: What comes into the plant? What goes out? What is the flow within the plant? Is there a functional connection with other plants in the vicinity?

Take up the different means of transport step by step.
Rail: Is there a rail spur into your plant? Follow it back to the main line if you can. Notice connections with other plants. Look at the cars on the spur or sidings. Are they short two-axle cars or long U.S. type (71)? Can you identify box cars (72), flat cars (73), tank cars (74), gondolas or hopper cars (75)? Are these full or empty? What color is the contents* (76)? Do you see special types of cars such as slag ladles or "submarines" for molten metal (77)?

In considering car shapes, look for the typical shadows of tank cars (humps along back) (78) or ore hoppers (79). Sometimes large tanks for chemicals are housed within ordinary box-cars.

Look at the cars standing about within the plant; they are probably near storage buildings.

Where does freight load and unload? Are there trestles or bunkers(80)? Is there a loading rack for liquids (81)? Follow rail lines within the plant; where the curves seem very short radius, remember individual cars can be pulled about by tractor or horses.

Does the plant have its own narrow-guage railroad, perhaps running to another plant or a storage or transshipment area(82)?

The plant may have its own rolling stock; look for the barns, and repair shop (83).

Look for rail lines running into buildings; here heavy metal castings, rolled shapes (84) or bulk materials are being handled (85). A small building through which rails run may be a weigh house (86). (True also for truck transport).

Try to distinguish rail lines from trolley lines bringing in workers; a town map is handy here (87).

Notice the direction of sidings and switches; it is sometimes possible to analyze the direction of flow on the basis that the lines *should* be laid out to avoid extra backing and filling (88). They may not be, however.

*Shiny surfaces such as coal may photograph light

Finally, be sure your railroad is really there; abondoned lines and roadbeds under construction can be confusing (89). Check necessary bridge where the rails or their shadows can be seen. Railroads with no traffic are always under suspicion. Although this is not strictly a part of your industrial analysis, it is worth noting that the presence of rolling stock at terminals can prove that a line is operational if you are sure of the route.

Water: Is the plant served directly by water transport, or by a short land run to a wharf nearby? Can you see barges or ships for ore, cement, coal, stone, timber, etc.(90)? How about tankers (91)? Timber and other items are sometimes floated in rafts (92).

Check the docks for heavy handling equipment, cranes, conveyors(93), etc. Is there a bunkering pier for liquids (94)? Maybe there is a special fenced area on the dock serving your plant.

Check the freezing dates. Can your plant move traffic all year? How about floods? Look along the bank for high water level marks(95).

Air: Is there a strip or field near your plant? Is your plant making parts of planes or otherwise serving the field (96)?

Road: Follow the roads and note signs of traffic. Are you sure you can tell a motor road from a railroad? Follow the turns; one sharp turn is enough to distinguish a highway (97). Highways also usually appear lighter, due to their smooth surface but not always. Truck routes often fan out cross-country during dry seasons (98).

Can your plant's product be moved by truck or under its own power? Look for truck types visible; they may tie in with ground reports(99). Do workers come in by truck or bus?

Pipelines for gas, steam, or liquids: Check around the perimeter of the plant for pipelines or earth scars (100); plants often supply steam to neighboring areas. Look also for drainage ditches and small water channels. Industrial waste flowing from a building may be a clue to process (101). Pipelines can often be picked up when they cross ditches. Very large pipelines will contain gas, used either as fuel or raw meterial (102). Linde liquid air plants, for instance, pipe in clean air from the country (103).

Power: Look for pylons bringing in the electric supply (104). The cable may be underground; sometimes you can pick up the earth scars (105).

The Flow within the Plant: Here you consider all means of transport, trucks, rail, pipelines, and especially heavy cranes and conveyor systems. Look for the high ends of conveyors (the shadows will help) (106). Material normally---but not always---moves up a conveyor.

Long conveyors may be broken into stages: There will often be a screening, cleaning or crushing process at the break. Horizontal conveyors are hard to distinguish from overhead passageways, cable or smoke conduits (107).

By now you will probably have a good idea of at least part of the flow within the plant (108). Sometimes raw materials will fan out through several alternative processes (109). Sometimes the layout is so complicated that no clear-cut flow is visible. Older plants which have been expanded present problems; new buildings may be interjected into the flow; making awkward operations (110). Sometimes the new plant exists side-by-side with the partly abondoned older works(111).

Remember that most industries have small sub-plants, by-products or contributory processes; for example, carbon-paste electrode plants or cryolite plants at aluminum works, bricquetting plants at coal mines or power plants, box factories or powder-bag shops at ammunition plants, sulfuric acid plants at film factories, a refractory brick plants at a blast furnace, etc. (112). Only ground information can disentangle such subsidiary processes.

Point 6) Identify the Storage:

In analyzing the traffic you will have found much of the storage within the plant. Now look for all visible places or containers where materials are stored. This includes warehouses, storage yards, stock piles, waste dumps, ponds and reservoirs and tanks.

Warehouses: You may find a group of sheds or buildings with plain gable or flat roofs (113), a single large building or two (114), or a wing or annex to the process buildings (115). The typical warehouse has no stacks and has rail spurs or roads running along the end or side. A group of warehouses separate from the plant can be distinguished from barracks by their closeness and by these roads or spurs (116). Crates or other shipping materials, sometimes the product itself will be often seen piled in the open nearby (117). The presence of extensive warehouse capacity means a bulky raw material or product subject to weather damage; for example, bauxite, cotton. Grain silos and elevators (118) are a special type of warehouse. So are cement (119) and bauxite silos (120). Magazines for ammunition or explosives are another special case; these are distinguished by protective blast walls or wide spacing (121).

Open Storage Yards: Here you will find weather-proof bulk materials such as ore, coal, coke, limestone (122), lumber (123) steel or iron scrap (124), castings, rolled metal products (125) and partly finished items such as M/V hulls (126), etc. Sulfur is also often stored in the open, and identifies itself by its whiteness (127). Look for the cars or other equipment used to bring the materials into the plant. Inspect the cranes or conveyors used to feed the materials into the process (128). The scoop-marks of overhead bucket or clamshell cranes will show on good photography. Try to guess in what order the piles are used. Reserve stock piles are generally smoothed down and show weather erosion (129). Try to estimate whether the storage yards are unusually full or empty (130). Is the supply seasonal, as in the coal supply of many European Russian plants?

Where metal pieces are visible in plant storage yards, it is sometimes difficult to tell which are finished products. Plants may have several mills or assembly shops where the product of one shop is the raw material of the another e.g., draw mills making rods, wire and nails (131).

Simple Stock Piles: These will be found in plants not fully mechanized: Asiatic plants formerly looked different from those in the U.S. in this respect (132). Stock piles are seen where small supplies are needed, for instance, at foundries a pile of sand is usually kept nearby (133). Piles of spoiled castings or wood models may be seen around metallurigical shops (134). An excess supply of some material may be simply piled in a vacant corner of the plant. In Russian sulfuric acid plants, pyrites may be seen piled about; this sort of thing is often difficult to tell from excavation spoil (135).

Slag and Waste Dumps: This is a special case of open storage. Waste usually fans out from a central dumping point, with spurs or roads built to the edges (136). Mine tailings are typically a sharp conical pile, carried up by a skip hoist (137). Sometimes cindery waste is used as fill or roadbed. The slag from steel smelters can be used to make cement, and a cement works will often be seen nearby (138).

The waste may be semi-liquid, as in the red mud pond which forms an identification feature of Bayer process alumina works(139).

Radioactive waste disposal should provide a recognition possibility for certain atomic industry installations.

Ponds and Reservoirs: Water is of course stored in the open; in the USSR open storage reservoirs for crude oil are also seen on World War II photography (140). These crude oil reservoirs may be circular or rectangular, resembling a large swimming pool. Such oil storage is usually distinguishable by fire moats or ditches (141). Open pits or reservoirs, when empty, are easy to mistake for tank or building foundations. Check for the incoming piping, often visible as a ditch or recent earth scar (142). Ponds or reservoirs always raise the questions, what is the liquid used for and how is it brought in? Filtering and aerating ponds or tanks will look like reservoirs, and may be discussed here. These are for aerating or cooling water by spraying jets into the air above a pond. When in operation, they can be seen as a fuzzy white appearance over the surface of the pond (143). Settling and sludging tanks will be found at water treatment plants and also where dust is removed from water used to clean gas, for instance, at a blast furnace plant. These are shallow circular ponds, sometimes covered. A typical sludge tank has a rotating arm carrying a spray, like the sweep hand of a clock (144). Slurry tanks in alumina works (145), poaching tanks and settling pits at pyrocellulose works (146) are also possible to mistake for reservoirs. Only a knowledge of the process involved at the plant will identify them. However, plain water storage and treatment is in general much larger than any of these (147).

Tanks: First, learn the shapes of the various types of tanks (148). Gas Holders are the largest. The older type "wet" gas holder are in collapsible sections which rise up and down within the steel framework depending on whether the tank is full or empty (149).

In the future, more spherical or fixed cylindrical gas tanks may be seen. You will see gas holders at coke ovens and blast furnace plants, synthetic oil and rubber plants, and wherever producer or synthesis gas is made. Natural gas for heating or other use is also a possibility.

<u>Tanks for Liquids</u>: When a group of the typical "asperin-tablet" gasoline or oil tanks are seen, the first thing to decide is whether it is simply a tank farm such as occur at transshipment points, or whether they are serving a nearby oil field, refinery or other processing plant. Crude oil or gasoline tank farms will usually consist of the same type of tank, unless all the products of a nearby refinery are being stored for transshipment, as at Gorky (150). A refinery, on the other hand will usually show different types, not only for crude and finished gasoline, which normally form the bulk of the capacity*, but also for fuel, lube oils, tars, high octane waxes, and volatile gases. Study the illustrations of tanks for different products; they will give you clues to process (151). Crude, low octane gasoline, kerosene, lube and fuel oils will be stored in fixed-roof tanks; high octane gasoline, being more volatile, is best stored in floating-roof tanks. (look for the shadow inside the roof line on partly empty tanks.) Groups of smaller fixed-roof cylindrical tanks may be for partially processed oils, or perhaps waxes or tars. Aviation gas components such as butane and alkylates are stored under pressure in spherical, or spheriodal tanks, or in sausage-shaped tanks which may be placed either vertically or horizontally (152). Look for the nipped-in corners of the shadows at the base of spheriodal or blimp-shaped tanks. If you can measure tank diameter <u>and</u> height, capacity can easily determined by using the capacity scale in the Photo Interpretation Handbook. Gasoline and oil may of course be stored in drums and 5-gallon cans, and stacks of these may be seen in the open (153). Strings of drums may be towed by a river-tug; the empties may serve as rafts (154).

<u>Chemical tanks</u>: Never as large as the big oil and gas tanks, and varied in shape (155). Racks of horizontal sausage tanks may store acids or solvents (156). A coke-oven by-product plant shows many shapes and sizes of tanks (157). The most identifiable tank, and one of the most important, is the hopper-type tank for ammonia. (See illustration #148) Without going into the possible complexities, inspect your plant for tanks, especially isolated tanks or small groups beside buildings, where a liquid is piped into the process or taken out of it (158). (For example, the caustic storage tanks in an alumina works.) Perhaps your tank contains fuel for a furnace or motor inside. You will usually not be able to determine exactly what such tanks are for without further,

*Crude oil stores will not of course, be seen at synthetic oil refineries.

information, but their presence may serve to tie down an important reported process.

Finally, there are some liquid chemicals which are shipped in crated carboys, for instance, formalin. Here you may never see a visible tank.

Water Tanks: Look for the typical water tower, usually easily picked out by the shadow of its framework base (159). Sometimes the base will be solid, and the tower can be mistaken for an isolated stack (160). Look for the earth scars running from the source and to the place of use. Shot towers, minarets and old castles have been taken for water towers. Water tanks will sometimes be found on hills, with a water line leading up from the pump station on a river or other water (161). Cisterns may also be seen on high ground.

A Final Word on Tanks: Unless the photography is very sharp and large in scale, you will not be able to be certain about the smaller tanks (162). Tall cylindrical tanks look like process towers or stacks. Banks of smaller tanks blur and look like buildings. The outlines of individual tanks lose their rounded character. Shadows obscure them. Even on large scale photography, condensers, absorbers and other cylindrical equipment cannot be told from tanks. Tanks may be roofed over completely for weather protection or camouflage. Do not expect certitude.

Camouflage: On photographs from World War II, large Russian oil tanks are sometimes seen to be camouflaged as square buildings (163). These can be spotted by a certain "abnormal" look; on clear photos such as those of Tula, the circular fire moats can be glimpsed at the sides (164). Another World War II camouflage device was netting, which turns tanks into blurry mounds (165).

Underground Storage: See the note on underground installations under Point 3. Oil tanks, of course are frequently buried or mounded over as a fire protection. (See illustration #45) Crude oil can be pumped into underground caverns. Mines and caves, when dry, form useful storage sites for certain purposes. Check roads or rail spurs which go into tunnels (166).

Point 7) Study the Utilities Supply:

Plants need electric power; steam for engines or heat; water, for steam, washing or cooling, and fuel such as oil, coal, gas, or other. Most of these you have already noted under storage, stacks; or traffic; now check them through.

Electric Power: Where does your plant get power? Many large Russian plants have the main power plant for the area on the grounds. Power can be the limiting factor in industrial production; before identifying an aluminum factory, for instance, make sure you have an adequate power source. Outdoor substations are often clearly visible, as are pylons and sometimes buried cable scars (167). In wooded areas the power line often runs through a cleared lane (168). Knowledge of the power available may help you to estimate the capacity of your plant. Both hydro-electric and thermal electric power stations are illustrated in the Photo Interpretation Handbook; a few examples and layouts will be included in the supplement to this text (169).

Steam: Check your plant for boiler houses, in addition to steam obtained from any thermal power plant nearby (170). Steam pipelines are large, because of the insulation, and can be identified by expansion bends (171). Buried steam pipelines usually affect the vegetation over them or melt the snow (172). Large boiler plants often supply heating steam to neighboring towns or industries.

Cooling towers and condensers: In addition to the typical cylindrical cooling towers, look for rectangular steam cooling "towers" which look like thin bricks standing on their sides (173). In both types, steam is condensed by passing over baffles; a certain percentage escapes and appears as a wispy cloud. (See illustration #65) Modern industrial practice eliminates more and more of this waste by cycling the steam through heat exchangers and other devices. If you see abandoned or demolished cooling towers, it may indicate new equipment rather than decreased operations (174).

Water: As noted above, water is used not only to create steam, but for cooling and washing. This latter use may require very considerable quantities. Have you located a sufficient water supply for your plant? Does the water need treatment or purification, or can it be used direct from a river or lake (175)?

Fuel: You have probably located the fuel supply and storage. Remember that alternative fuels may be used when the conventional supply is scarce. Are there peat cuttings near your plant (176)? If coal is used, is it solid or reduced to dust and fed by blowers? This may account for extra structures in the coaling system.

Point 8) Special Recognition Features:

Here you are concerned with those special industrial installations or equipment whose appearance must be memorized in order to recognize the industries containing them. Some, such as coke ovens, are the industry in question. Others, like rotary kilns, are found combined with different equipment in several types of plants.

Of course, all those items you have already checked are "special features" of industry. The structures listed in this section are found in certain industries only and point to specific processes.

No such list can be final. Experts in each industrial field will desire to add certain specialized structures not known to the general interpreter. Priorities change; specialized structures become crucial targets. Minor differences become significant. Old equipment is put to new uses. New equipment appears. This, however, will give you a basic list of industrial recognition features with which you can reasonably expect to become familiar and which are found in the major industries as they are seen today:

Electric Power Plants (177)
Coke Ovens (178)
Blast Furnaces and Hot Stoves (179)
Bessemer Building (180)
Open Hearths Building (181)
Rolling Mills (182)
Aluminum Pot Rooms (183)
Smelters for Copper, Lead, Zinc (184)
Vertical, Rotary, & Horizontal Kilns (185)
Foundries with Cupola Furnaces (when visible) (186)
Forges (187)
Nitroglycerin Plants (188)
Nitric Acid Absorbtion Towers (189)
Electric Substations (190)
Pipe and Shell Stills (191)
Oil Derricks, Jacks and "Christmas Trees" (192)
Fractionating and Alkylation Towers (193)
Gas Cleaners, Scrubbers, Precipitators (194)
Hydrogenation Stalls (195)
Mine Heads (196)
Quarries and Open-pit Mines (197)
Aero-Engine Test Beds (198)
Shipyard Ways and Dry Docks (199)
Test Basins (200)
Wind Tunnels (201)
Gun Test Ranges (202)
M/V Test Courses (203)

Plus:

1) Storage structures already discussed, including particularly the various types of tanks, gas-holders, magazines, and silos

2) Transportation equipment already discussed

It should be noted here that recognition features must be used as parts of a pattern. Hydrogenation stalls make sense as part of a Bergius synthetic oil refinery; they do not make sense in a shipyard. The presence of a gas-holder influences your decision about whether certain installation is a retort for water gas generation. The advanced recognition clues are the relations between things, which are grasped after you have learned the appearance of the things in isolation.

Point 9) Check for Construction, Destruction & Operational Status:

Be sure to look your plant over carefully for new construction; foundations for new buildings, tanks, pits, ditches for utilities lines, fencing-in of additional area, new roads or rail beds, construction materials piled about (204). Photos taken at different dates should be compared to pick out changes. On wartime photography, it is sometimes hard to distinguish construction from destruction. Recent destruction is disorderly and irregular; look for charring or blast damage on adjacent buildings (205). It is sometimes clearly possible to tell HE blast holes from fire gutting (206). Note---after the rubble has been partially cleared, and reconstruction started, it becomes more and more difficult to distinguish from construction; only comparison with previous cover can help here (207). Damage to structures under construction is hopeless to analyze without comparative cover. Demolition is a special case of construction, usually found with evacuation of plant equipment. Ground report will indicate this. In some cases, the retreating owners knocked out central supports, allowing walls to collapse more or less whole, to facilitate reconstruction. Even gutted plants are worth analyzing, because of the practice of rebuilding on the same sites, thus saving new engineering, and making use of the foundations, railbeds, utility lines etc. which constitute so much of the labor of plant construction (208). Your check of construction and destruction and your stack and smoke count, will have covered most of the question of operational status, and conversion so far as this can be observed. Conversions from gun stocks to furniture cannot be seen, of course; but you can see a fertilizer factory at an explosives plant. Notice new traffic patterns, signs of disuse of roads and structures in parts of the plant (209).

Point 10) Note Security and Defenses:

How important is your plant? Security measures, fencing, guard posts, militia units, gun positions, watch dog kennels, camouflage, searchlights, all give indications (210). There may be special air-raid bunkers for personnel. Fire protection is also a security measure; fire control apparatus will be housed in a garage or fire control point (211).

Note: On wartime photography of the European USSR, you may see plants surrounded by ground fortifications and AA positions, in which that particular factory was defended from a terrain or tactical point of view rather than because of its industrial significance (212).

Point 11) Locate the Labor Supply:

Where do the workers come from? Look for barracks, housing develepements, residential suburbs (213). Look up the location and numerical designation of POW camps in the area; this will help you tie in with ground reports, and you may occasionally be able to verify or deny them from this point alone (214).

How are the workers brought in? Are new labor barracks under construction in the area? Conscript camps are difficult to tell from military barracks without research, except in cases where the equipment of armored units, or obvious connection with airfields, etc. can be seen.

You may note special housing for managers or technical personnel.

In considering plant personnel as a whole, remember that some of the plant buildings may well include canteens, first aid station, clothing or food warehouses, etc.

Point 12) Make Sure There Are No Significant Unknown Factors in the Envirnment:

Before you call your analysis complete, be sure you have not overlooked background facts which might change your opinions. Everyone who has analyzed industries in unfamiliar areas sooner or later has the experience of drawing false conclusions because of ignorance or some local factor. Is there a sister plant nearby performing some part of the process? Where is your product to be used? If it is perishable or sensitive, can it be transported that far? What about the raw meterials called for? Are they available? What are the natural resources or special industries of the region? Agricultural crops can prove baffling; the labor camps you see may be for seasonal workers; drying sheds or silos for produce may have been interpreted as part of your industrial complex. Sometimes an agricultural byproduct will serve as fuel. Puzzling appearances may be resolved by a knowledge of climate; do high floods occur? Does extreme cold or heat require special construction? Intense winds (215)? You have of course ascertained where the nearby cities are; how about big rail or water junction points? Very old historical towns or Czarist industries may preserve their outlines in the midst of new structures when see from the air. The outlines of old city blocks can sometimes be traced in the grounds of new plants (215). Prehistoric mounds or town walls are visible in the growth pattern of long-cultivated fields (217). Local activities, perhaps religious, or perhaps surveying or scientific experimentation, may be noticeable (218). Asian tombs, monuments and cemeteries have been confused with many things including gun positions (219). Has there been a sweeping political or economic program affecting your area(220)? This may explain an apparently irrational order of construction. Is a new rail line or canal coming into the area?

This does not mean that you must know everything about everything before you can analyze a plant. Much of what you learn will not be used in a quick one-time survey, or will at most be used to satisfy you of the correctness of your analysis. As you continue making such analysas, however, you will find that "extra" information from one area enables you to make quick correlations in another. When new photography of one of your plants comes to hand, your information on the environment will give you an understanding of the significance of changes in the whole pattern. In your experience in dealing with intelligence from visual records, you will soon appreciate the usefulness of what may at first seem to be mere curiosity.

Finally, it is always worthwhile to look for ground photographs of your plant. Old photographs may show buildings under construction and equipment being installed (221). It is often possible to confirm the operational status of a reconstructed plant by using recent ground photography in combination with those taken during the war (222).

TAB

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# BASIC INDUSTRIAL PHOTO INTERPRETATION

Chapters 7 through 15, 27, and 28 extracted from "Photo Intelligence for Combat Aviation," Army Air Force School of Applied Tactics, April 1944 (A1164-15C)

Subjects:

- Hydro-Electric Power Plants
- Thermal Electric Power Plants
- Coal
- Coking and Gas Plants
- Petroleum
- Chemical Industries
  - Synthetic Fuels
  - Synthetic Rubber
  - Nitrogen Fixation
  - Explosives
- Iron and Steel
- Aluminum
- Assembly Industries
- Lumber and Pulp
- Cement and Lime Plants
- Ceramic Plants
- Shipbuilding Yards
- Transportation
- Industrial Clues
- Industrial Camouflage

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HYDRO-ELECTRIC POWER PLANTS

1. A hydro-electric plant depends upon a constant source of water at some elevation above the generating plant. They usually are situated in hilly or mountainous country. In the United States, about 40% of the commercial electric power is produced by hydro-electric plants. Scandinavia, Southern Germany, Italy and Japan are well supplied with hydro-electric plants. In these plants the energy of falling water is used to turn water turbines which drive the electric generators. The turbines are very efficient. The quantity of water necessary depends upon the height from which the water falls. The greater the fall or "head," the less volume of water necessary to produce a given amount of electric power.

2. Water to operate hydro-electric plants is stored in natural lakes or behind dams. Where the water is stored behind a dam, it is usual to erect the generating plant in or at the foot of the dam. When a natural lake is used and in some cases of artificial lakes, the hydro-electric plant may be a mile or so away at a lower elevation. The water is carried to the water turbines in penstocks. These hugh pipes may lie on the surface or be buried. Sometime, they are tunneled through solid rock. When a hydro-electric plant is composed of several generating units, it is possible to determine how many are in operation by the number of points discharging expended water into the "tail race."

3. Hydro-electric power plants may be recognized by their position close to a dam or near a lake, the penstocks and tail race, the transformer stations and distributing high lines. The plants themselves are relatively small concrete or masonry buildings.

4. The electricity generated by a hydro-electric plant may be used locally or transmitted long distances. If the current is to be used locally, it may be distributed to the consumers at the voltage generated. Because the line drop is about 1000 volts per hundred miles, current to be distributed is stepped up to 110,000 or 220,000 volts at a transformer station close to the power plant. From this station the current is carried across country on cables suspended from steel towers. The paths of these "high lines" are direct and easily recognized. The distance between the individual cables of a high line is related to the voltage of the current carried.

5. Transformer stations are rarely recognizable on photographs with a scale less than 1:10,000. On larger scale verticals they appear as small rectangular structures composed of a framework of light steel surrounding the transformers and forming a unit in a high line. Sometimes, one is found on the roof of the generator building.

# THERMAL ELECTRIC POWER PLANTS

1. Thermal electric power plants are more frequently seen than are hydro-electric plants. The fuel used is usually coal. Some plants utilize fuel oil or gas. These are usually small plants. Commercial thermal electric power plants should be sought close to a cheap means of transportation. They will be on the waterfront or a canal if fuel can be brought in by ship or barge; otherwise, they will be serviced by a railroad. The size and number of the chimneys and size of the fuel reserve are incongruous with the size of the building. This makes the installation easy to recognize. Since the water used in the boilers is used over and over again, a condenser system is incorporated in the plant. In most European plants this is in the form of huge, out-of-doors cooling towers. These may be as much as 100 feet in diameter, and when in operation they show a slight plume of steam. The fuel stock piles are accompanied by various types of handling machinery - bucket hoists, cranes and endless belt conveyors. A small transformer yard may be visible close to the power plant. The power may be distributed by overhead or buried cables.

2. Commercial steam plants closely resemble thermal electric power plants. It is often impossible to determine the difference. Usually, it is possible to recognize two sections in a thermal electric plant, the boiler room and the generator room. Usually, a thermal electric plant has a transformer yard. A steam plant does not have a generator room nor a transformer yard.

3. The power plants for industrial installations are usually double-purpose, producing both steam and electricity for use in the factory. Whether it is a steam or thermal electric plant, its location in the entire installation can be determined by the presence of the tall chimney or chimneys and a fuel supply. However, if the electric power is produced by a diesel-driven generator, it may not be possible to locate the power house. Sometimes, the exhaust vents or fuel tanks will give a clue to its position.

COAL

1. Coal is the principal fuel. It is found in a variety of forms with differing qualities and uses. Anthracite or hard coal and bituminous or soft coal are the principal forms. The former is useful solely as a fuel. The latter, being rich in hydrocarbons, is the source of many useful products, such as coke, gas, coal tars and other chemicals. These coals can be stored without affecting their fuel value. The third principal variety is lignite. It is a poor fuel, but the source of many valuable products and is the basis of Germany's chemical and synthetic industries. It does not store well. Because of this, it is mined as it is used and no above-ground reserves are accumulated.

2. Anthracite and bituminous coals usually are shaft mined, lignite by stripping in open pits. Shaft mines can be recognized by the mine head buildings and hoists, the power house to operate the mine machinery, sorting house to clean the coal of slate and other gross impurities, pumping station, dump piles of waste, and stock piles of mined coal ready for shipment, transportation facilities and handling equipment, conveyors, cranes, hoppers, etc. The color of the stock piles will generally identify the material as coal.

3. An extensive shallow excavation with many railway tracks radiating through it and long low piles of a dark substance between the tracks are characteristic of an open pit lignite mine. The actual mining may be done by small "steam shovels" or manually. Light loading equipment may be found if the scale of the photographs is large enough. There are only a few scattered small buildings associated with the mine. Transportation for the lignite may be either railway or canal. There may be loading facilities for the transport agent. An industrial plant utilizing the lignite may be adjacent to the mine. There may be a briquetting plant at the mine.

 

COKING PLANTS*

1. Bituminous coal and lignite are destructively distilled and produce coke, illuminating gas, ammonia, coal tar, and many other chemical substances. An installation performing this process is called a coking plant. A coking plant is composed of coking ovens, scrubbers, gasometers and chemical recovery installations. The coking ovens are long, narrow, rectangular buildings with a tall stack at either or both ends. One part of the building is tall. This section contains the grinders and charging equipment. The building is flanked by railway spurs. On one side the coal to be coked is received and transferred to the individual ovens. On the opposite side, the railway carries the cars that receive the finished coke from the ovens. The red-hot coke is pushed out of the narrow oven by a ram operated from the charging side. The coke bursts into flame as it strikes the air. As soon as a car is loaded it is run under a quencher. Here, quantities of water are showered upon it. If the quencher is open, a great cloud of steam arises. This is wasteful of heat, so in modern plants the quencher is closed and the steam produced is put to work. Along the top of the ovens are huge pipes that load off the gases produced in the ovens.

2. The gases are led from the ovens to the condensers where the liquifiable substances are removed. In this process the gases are cooled. The liquid substances are stored in small outside tanks, usually close to the condensation plant. The building housing this process has no other characteristics. From it the cooled gases pass through the scrubbers where the ammonia is removed. The water from the scrubbers is neutralized with sulphuric acid and then evaporated to recover the ammonium sulphate. The washed gases from the scrubbers are piped to the gasometers for storage, either close by or some distance away.

*See Photo Industrial Study No. 3
"Coke, Iron and Steel"

3. The gasometers are large cylindrical metal tanks. There are two general types, wet and dry. Wet tanks float in water like an inverted tumbler partly filled with air. The gas in the tank supplies the buoyancy. Wet gasometers are surrounded by a lattice of steel girders. As the volume of stored gas changes, the tank moves up and down within this lattice. Dry gasometers differ in two observable respects. They are not surrounded by a steel lattice and they are always the same height. The adjustment to the volume of gas in storage is made by a huge internal piston that operates from the bottom of the gasometer.

4. Another widely used type of fuel gas is made from coke. It is called water-gas. This is made by forcing steam through white-hot coke in the absence of air. The installation resembles a small set of coking ovens. There is no quenching tower or large chemical building in a water-gas plant, only oven-like chambers, a tall stack and loading devices, boiler house, a pumping station and stock pile of coke. As in a coking plant, the gasometer may be close by or at some distance. A producer-gas plant is a similar installation in which a stream of hot air is substituted for the steam.

5.

PETROLEUM*

1. The discussion of petroleum can be divided conveniently into four parts: production, transportation, refining and storing. Spotted here and there over the earth's surface are areas beneath which are pools of crude oil. These pools are reached by drilling a hole down into them. After the pool has been tapped by a well, it is often expedient to leave the "rig" or derrick that was used to handle the drill in place. They are built in a slender pyramid of light steel or wood beams. Their shadows at once identify them. The wells in a field are connected with the pumping station and storage tanks. The power for pumping may be produced on the field at one or more power plants or be supplied by a "high line."

2. Oil fields are frequently in isolated areas away from the regions where the petroleum products are to be used. The crude oil is usually transported many, even thousands, of miles to the refinery. Three methods are used, often in combination: tank car trains on railways, tank barges or ocean tankers on waterways and pipe lines. Pipe lines may be hundreds of miles long. They follow the straightest possible route. Along their course are pumping stations to keep the oil moving. Pipe line routes may be recognized on aerial photographs as narrow light lines cutting straight across the country. They may be swung across rivers and ravines by suspension cables. They may cross some rivers in a trench blasted into the bottom.

3. The destination of crude oil, whether it is carried by tanker, tank car or pipe line, is the refinery. Here , the crude oil is fractionally distilled and the various products of commerce separated. The most important of these are gasoline, kerosene, lubricating oils, greases, parafin, pitch and oil-coke. The principal installations at a refinery are the stills and power plant. Every photo interpreter should be able to make a preliminary report on an oil refinery, but only a petroleum technologist can be expected to write a comprehensive report. The batch stills are horizontal cylinders that look like a boiler. At one end is a vertical element and a lot of piping called the fractionating tower. At the other is the boiler house with its accompanying tall stack. In older installations a battery of batch stills is operated from a single boiler house. In modern plants each still has its own boiler house. Steam produced in the boiler house is piped to the still, where it vaporizes the crude oil. This vapor flows into the fractionating tower, where the different products are led off by pipes at different levels, usually the least volatile at the bottom, the most volatile at the top. From the tower the fractions may be led to other stills for further refining or to

*See Photo Industrial Study No. 3
"The Petroleum Industry"

storage tanks. The boiler house, the horizontal still, the fractionating tower and its maze of pipes, identify a petroleum refining unit.

4. "Cracking" units are a particular type of petroleum still that increases the yield of the more volatile fractions during the distillation. There are several different processes used for this, and in each plant the details of arrangement differ. In a preliminary report these units need not be separated from the stills.

5. Power houses are recognized by their usual characteristics. Other buildings associated with a refinery are control houses, usually small and near the stills; administration buildings, usually at the edge of the installation near a highway; laboratory, usually near or in the administration building.

6. Before and after passage through a refinery, crude oil and its products are stored in tanks. Groups of these tanks are called a tank farm. Tanks for storing various types of petroleum products differ somewhat in size, form and dispersal. In general, those products that are inflammable are stored in well dispersed tanks, each surrounded by a low revetment. These revetments are designed to contain the capacity of the tank in case of damage. Farms for the storage of crude oil are made up of the largest size tanks. Gasoline and kerosene are stored in similar but smaller tanks. Some of the high-test gasoline tanks can be recognized by floating lids. Such lids are used to reduce losses through evaporation and to reduce the fire hazard from accumulated vapor in the tank. (Recent technique in the United States uses a spheroid tank for storing highly volatile products, like aviation gas. In these tanks the liquids are kept under pressure.) Some of the gaseous products, such as butane, are kept under pressure in horizontal cylindrical tanks with round ends. These are variously called blimps, bottles and bullets. Lubricating oils are stored in small cylindrical tanks.

7. a. The capacity of a cylindrical tank can be estimated by the following formula:

(1) $L \times \left(\frac{D}{2}\right)^2 \times 3.142 =$ volume in cubic feet

when L = length in feet
D = diameter in feet

(2) Volume in cubic feet x 7.48 = U.S. gallons

(3) Volume in cubic feet x 0.178 = U.S. petroleum barrels

b. The capacity of a bottle can be estimated by adding one-third of the length of the rounded ends to the length of the cylindrical portion and using the above formulae.

c. The volume of a spheroid can be estimated by the following formula:

$$\left(\frac{H + D}{4}\right)^3 \times 4.189 = \text{volume in cubic feet}$$

when D = diameter in feet
H = height in feet



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# CHEMICAL INDUSTRIES

## GENERAL

1. No hard and fast definition can be given for a chemical industry. There are, in fact, very few industries into which chemistry does not enter. The term is used here for those munitions industries in which chemistry plays a major part. Some of them are born of war, others are normal to peacetime economy. The synthesis of fuel and rubber substitutes are chemical industries brought about by war. The fixation of nitrogen, war-born in 1913, is now a peacetime industry expanded for war. The development of the chemical industries in peacetime is an excellent indication of the technological development of a nation. It is probable that no nation is chemically self-sufficient.

2. There are so many different types of chemical plants that no person can be expected to recognize all of them. Many plants bear no outward indication of the industry contained. Only a few of the industries most important to the Axis nations need be recognized by all photo interpreters. These are synthetic oils, synthetic rubber, fixation of nitrogen and explosives. There are a few general characteristics common to many chemical plants. When they are found, a chemical plant should be suspected. These are,

   a. An accumulation of cylindrical tanks often quite varied in size and erected in clusters.

   b. Considerable overhead piping that connects buildings with buildings or tanks.

   c. Vented roofs and tall fume stacks.

   d. Buildings of various shapes and sizes placed with little regard to an aesthetic arrangement.

SYNTHETIC FUELS

1. Truly synthetic motor fuels are of two varieties - hydrocarbons, which are substances like gasoline; and alcohol-plus-ether mixtures. The former are made from coal, air and water. The latter are produced by fermenting sugars or starches or by direct synthesis from coal, air and water. Much alcohol is produced by former liquor distilleries. Both types of motor fuel are used by the Axis.

2. The most important synthetic motor fuel is the hydrocarbon. It is made by hydrogenating coal. In this process the coal is finely pulverized and mixed with oil to make a paste. The paste is heated and pumped into converters, where under high pressure it is forced to combine with hydrogen. The product is then separated into fuel gas, motor fuel, a heavy oil portion that is used to make further paste, and unreacted coal. Only about 5 per cent of the coal remains unreacted. One ton of coal will yield about 40 gallons of motor fuel, 50 gallons of Diesel fuel, 35 gallons of fuel oil, and 10,000 cubic feet of fuel gas. The most modern German process uses a catalyst in the hydrogenation and has a much higher yield of motor fuel and correspondingly lower yield of heavy oils.

3. There are certain features of any synthetic fuel oil plant that can be recognized on aerial photographs. The plant resembles an oil refinery with an overabundance of buildings. Look for these:

a. Extensive stock piles of coal and possibly a coal mine close by.
b. Plentiful supply of water.
c. A hydrogen producing plant. If electricity is available in quantity, this will be used to electrolyze water. Then, a battery of electrolytic cells, usually in a small cubic building, will be found connected by large pipes to a wet-type gasometer. If electricity is not available, the hydrogen may be produced by the water-gas method and stored in a wet-type gasometer.
d. A hydrogenating plant which will consist of a compressor, often housed in the boiler house, and the converters, tall slender cylindrical structures flanking a larger cylindrical pre-heater, all connected by pipes with the gasometer through the compressor building. The hydrogenation units are usually separated from the rest of the plant by a tall brick fire-wall.

e. A coal-grinding and paste-making plant usually connected with the stock pile by means of a conveyor system and with the hydrogenation plant by huge pipes leading through a pumping station. Tanks for the heavy oil used will be found near this installation and connected with it.
f. A battery of oil refinery stills and a tank farm.

4. A preliminary report on a synthetic oil plant should state:

   a. Location and overall dimensions in yards.
   b. Transportation facilities.
   c. Size of the tank farm.
   d. Defenses.

SYNTHETIC RUBBER

1. Synthetic rubber plants, like synthetic oil plants, are large and complex. The two easily may be confused by the photo interpreter not specializing in industrial installations. The most noticeable difference between the two is the lack of a large tank farm in a synthetic rubber plant.

2. There are three principal starting points for the synthesis of rubber-like compounds (lastics). These are acetylene, butadiene and alcohol. Of these, only acetylene is of importance in Germany. The raw materials for producing acetylene are coke, limestone and water. The acetylene is put through a series of complex chemical changes to form a variety of compounds which are ultimately combined to make any of a half-dozen or so lastics. The process entails five distinct stages: preparation of coke, preparation of acetylene, synthesis of lastic producing chemicals, synthesis of the lastic, curing and finishing the lastic.

3. The coke is produced in orthodox fashion and the coking plant contains the usual chemical works and gasometers. The coke is then mixed with limestone or lime and subjected to very high temperature in an electric furnace to form calcium carbide. This carbide furnace may be recognized by the power line leading to it and its tall slender fume stacks. A gasometer may be connected with the carbide plant. The acetylene gas is then formed by reacting the carbide with cold water. This reaction generates considerable heat which must be controlled so the acetylene building will be situated near one or more characteristic cooling towers. Acetylene is rarely stored; it is too dangerous a gas to have around in any quantity. The gas is piped to a series of tall towers where it is purified - freed of dust and water vapor. From the purifying tower the gas is led to another series of towers where it is synthesized under high pressure into the lastic-forming chemicals. Some of these substances may be stored in small tanks. The lastic-formers are combined to make a latex or "rubber milk" which is coagulated by means of acid to form the crude lastic. This operation takes place in a building with no aerial characteristics. The lastic is washed, sheeted and dried in large low buildings. The drying plant usually can be recognized by its size and adjacent boiler house. Frequently, the fuel used is gases from the coking or carbide plant.

4. The preparation of a report on a synthetic rubber plant must be done by a technical specialist. The general photo interpreter should be able to recognize the plant and should report its location, size, transportation facilities, high line, water supply and defenses. (See par. 4, above).

THE FIXATION OF NITROGEN*

1. Free nitrogen in the atmosphere is fixed in compound form by either of three processes: the Arc process, which produces nitric acid directly; the Haber process and the Cyanamide process, which produce ammonia from which nitric acid can be made. The Arc process requires an abundance of cheap electricity and is of minor importance except in Norway and a few other isolated places. By far the greatest part of the nitric acid used by the Axis is produced by the Haber or Cyanamide processes. Plants using either of these processes have certain characteristics by which they may be recognized from the air. A complete study of plants for fixing nitrogen is a task for a technical specialist, but the general photo interpreter should be able to recognize such an installation.

2. The Haber process involves several stages: the preparation of pure hydrogen and nitrogen free of oxygen, the synthesis of ammonia from these gases and the oxidation of ammonia to nitric acid. The hydrogen may be procured from either of two sources. If electricity is available in large quantity the hydrogen will be produced by electrolysis. (See par. 3, c, above). Otherwise, it will be extracted from water-gas (Bosch process) or any other mixed gases rich in hydrogen. The nitrogen is extracted from the air or producer gas by liquefaction, or it may be prepared by burning the oxygen out of the air. The buildings in which the gases are extracted are large rectangular structures that are well ventilated and connected by large pipes to nearby gasometers. Since the manufacture of ammonia requires three times as much hydrogen as nitrogen, two sizes of gasometers will be found. The larger will store the hydrogen.

3. The nitrogen and hydrogen are mixed and compressed in a building similar to that for extracting the gases. Adjacent to it or as a part of it is the converter building where the two gases are combined to form ammonia. This building or wing is tall (80 to 90 feet) and narrow, housing tall cylinders built to withstand a pressure of seven tons per square inch.

*See "Nitrogen and Associated Industries," Photo Industrial Studies No. 1, Office of Assistant Chief of Air Staff, Intelligence, Washington, D. C., 1943.

4. The ammonia may be stored either compressed and liquefied or dissolved in water. Liquefied ammonia is stored under pressure, usually in hopper tanks. These are squatty cylindrical tanks with hemispheric bottoms and connected at the top by narrow catwalks. They can be identified by their shadows. The solution of ammonia in water is stored in conventional tanks.

5. The Cyanamide process employs a totally different method for making ammonia. Calcium carbide is formed in an electric furnace from coke and quicklime. (See par. 3, above). The carbide is then treated at high temperature with hot nitrogen under pressure. This converts the carbide to calcium cyanamide. The cyanamide is treated with superheated steam and the reaction produces ammonia and calcium carbonate. The ammonia is stored as in the Haber process. From this point on the processes are alike. These are characteristic of a cyanamide plant:

a. Stock piles of coke and limestone
b. Rotary lime kiln
c. Carbide furnace and cyanamide ovens
d. Large transformer yards
e. Large steam plant
f. Ammonia building

6. The ammonia is led through pipes to a building where it is oxidized to nitric acid. This building has no distinctive features, but it is always associated with the nitric acid absorbers. These may be any of four types, each distinctive and sure indicators of nitric acid production.

a. Granite or acid-proof brick towers, usually polygonal in cross-section, about 25 feet in diameter and 100 feet high, connected across the top with a catwalk. These look like a group of five or 10 huge silos.
b. Stainless steel towers of about the same dimensions and capped with a hemispheric dome. These reflect light almost aswell as a mirror. The cluster of towers will be surrounded by a catwalk.
c. Horizontal Fauser absorbers, a series of large cylinders arranged on an incline alongside or on the roof of the nitric acid plant. These cylinders are about eight feet in diameter and 40 feet long.
d. A second type of Fauser absorbers uses vertical stacks of four to six pairs of horizontal cylinders. The The individual cylinders are about two feet in diameter and 20 feet long.

7. The buildings for concentrating and storing the nitric acid are not distinctive. The acid may be shipped in glass carboys or special chemical tank cars. The acid may be used at the plant where it is produced. The two principal uses are the manufacture of explosives and of fertilizer.

8. Plants producing synthetic fertilizer are usually easy to recognize. Generally, they are a relatively small tall building adjoining a lower very long structure with either a simple ridged or arched roof. The material is manufactured in the tall building and stored in the long building.

EXPLOSIVES*

1. Plants manufacturing explosives almost always are isolated and some distance from any community of size. They are well serviced by transportation facilities. Internal transport may be entirely over a network of highways. The individual buildings are small and dispersed. Those in which the explosives are made, stored and packaged, are surrounded by blast walls and may be partially buried.

2. Explosive plants should not be confused with ammunition dumps. The plant will have a power house and a variety of large and small unrevetted buildings in a cluster slightly removed from the manufacturing area. Such an arrangement is not found at an ammunition dump.

*See Photo Industrial Study No. 6
"The Explosives Industry"

# IRON AND STEEL*

1. Two items predicate the location of a steel mill: plentiful labor and adequate transportation for the raw materials and finished product. Steel mills will always be found on railways or navigable waterways. They are very complex industrial plants covering considerable area. These are the important sections in a steel mill:

a. Stock piles and handling equipment
b. Blast furnaces and their adjuncts
c. Steel furnaces
d. Rolling mills
e. Forge shops
f. Foundries
g. Stock yards

In addition, there often are,

h. Fabricating shops
i. Wire and nail mills
j. Coking plant

2. The stock piles are always close to the blast furnaces and near the principal means of transportation. They are huge bins in which are stored the working reserve of raw materials, ore, coke and limestone. Railroad sidings and unloading machinery flank them on one side and the blast furnaces on the other.

3. The blast furnaces are about 25 feet in diameter and from 60 to 100 feet high. Associated with each is a battery of two to six hot stoves to heat the compressed air before it is injected into the bottom of the furnace. Abutting the furnace is a covered working platform alongside of which is a railway spur for the "pig boats." Connecting the hot stoves and the furnace are huge pipes to carry hot gases from the top of the furnace to the heaters of the hot stoves and hot compressed air from the hot stoves to the furnace. The hot stoves in turn receive the compressed air (through equally huge pipes) from the blasting engines in a nearby building. This building usually houses the steam and electric power plants in addition to the blasting engines. The tall stacks locate this building.

4. Only about 25-30 per cent of the pig iron produced in blast furnaces is cast into "pigs." (In some plants all of the iron is cast into pigs). Most of the pig iron is carried in football-shaped "pig boats" to the furnaces that convert it into steel. The most common method used today employs the open-hearth furnace. The other two methods employ the Bessemer converter or an electric furnace. Of these, the latter is met with least frequently.

*See Photo Industrial Study No. 3
"The Coke, Iron and Steel Industries"

a. Open-hearth furnaces are housed in long low buildings serviced with a railway from the blast furnaces and equipped with a row of widely spaced slender tall stacks. Each stack represents an open-hearth furnace.

b. Bessemer converters will be found in buildings serviced by railway from the blast furnaces. They may draw air from the furnace blasting engines or from a blasting engine house of their own. The products of combustion usually leave a tell-tale white powder on the roof of the converter building in the area surrounding the vents. The finished steel is poured into ingot moulds or ladles mounted on railway cars. The ingots are hauled to the rolling mill, the ladles to the foundry.

5. The rolling mill is a long broad building. Most of them can be recognized by the roof construction. In these, the mill seems to be, and actually is, four buildings abutting each other, the ridge line of the first and third being at right angles to the ridge line of the second and fourth, the longest portion of the mill. The first section houses the soaking pits, where the steel ingots are heated to the proper degree of redness for rolling. From there they are passed to the billet mill where these huge blocks of steel are squeezed down to bars or "billets," six or eight inches square and cut into convenient lengths. By this time the steel has cooled too much for further rolling and it is passed to the second transverse section, which houses another set of soaking pits. From these it is put into the rolling mill proper and squeezed into the required shape and thickness and cut to length. At the end of the rolling mill is a storage yard for the finished product. Here are a traveling crane and a siding.

6. Adjacent to the rolling mill is the lathe shop where the rolls for the mill are made and rebuilt. There is a yard between the mill and the shop in which are stored the rolls not in use.

7. Forge shops and foundries are difficult to recognize unless the scale of the photograph is large and the interpreter is familiar with steel mills. Forge shops usually have a nearby stock pile of steel ingots, and often show a discolored roof over the forges. Foundries are always connected by rail with the steel furnaces and blast furnaces. Piles of wooden models and moulding sand are usually found outside the building. However, wooden models will also be found outside the model shop in which they are made. The stock yards adjacent to the buildings may give a clue to the function of the shop.

8. A variety of other buildings, small and large, will be found in a steel mill, such as administration building, hospital, pumping-stations, general shops, fabricating shops and small piece shops.

ALUMINUM*

1. The extraction of aluminum is divided into three stages, usually carried on at greatly distant places: mining, preparation of alumina (the purified oxide of aluminum), and reduction of the metal. Bauxite mines sometimes are found in close conjunction with the plants that convert the mineral to alumina, but more frequently these two parts of the aluminum industry are apart. The mines themselves are of little interest to photo interpreters and will not be described. The alumina production plants vary considerably, depending to some extent upon the process that is used. However, there are a few characteristics by which they can be recognized. The electrolytic plants for producing aluminum are characterized by several distinctive structures.

2. The process by which bauxite is converted to alumina involves four stages: grinding, digestion, precipitation and roasting. Because the ore is affected by moisture it is carried in closed hopper cars and reserves are stored in a covered structure. From storage it is carried on a conveyor belt to the top of the rock mill, where it is ground and pulverized. This building can be recognized by the white powder on the roof and surroundings. The powdered ore is conveyed to the digesters, a series of tanks, where it is mixed either with a solution of alkali or acid, depending upon the process used. The solution is subjected to heat and pressure. This dissolves the aluminum compounds from the ore, leaving the impurities as a reddish mud. Tanks of digesting fluids and a boiler house always accompany the digesters. The solution of aluminum compounds and red mud are passed through a filter plant and the red mud discharged to form a "red mud lake." This is highly characteristic of all alumina producing plants. The filtrate is then stored in huge round vats called the precipitators. In them the aluminum compounds are converted to aluminum hydroxide which is a gelatinous mass that slowly settles and is concentrated and washed by various means. The aluminum hydroxide produced is about 99.5 per cent pure. It is conveyed to rotary kilns where it is roasted to alumina. The finished alumina is stored under cover, and shipped under cover to the electrolytic reduction plants.

*See Photo Industrial Study No. 4
"The Aluminum Industry"

3. The clues characteristic of an alumina producing plant are,
   a. Covered storage facilities
   b. Rotary kilns
   c. Digester, alkali or acid storage and precipitation tanks
   d. Red mud lake
   e. Plentiful supply of water

4. A preliminary report on an alumina producing plant should be based on the following check list:
   A. General
      1. Location, distance and direction from nearest easily recognized settlement, overall dimensions in yards.
      2. Transportation facilities

   B. Buildings
      Location and dimensions in feet for each of the following when recognizable:
      1. Bauxite storage
      2. Rock mill
      3. Digesters
         a. Number of digester tanks
         b. Alkali or acid storage tanks
         c. Boiler house
      4. Pumping station
         a. Source of water
         b. Distance from boiler house
      5. Filter buildings
      6. Precipitator
         a. Number of tanks
      7. Kilns
         a. Number of tall stacks
      8. Alumina storage
      9. Shipping docks
         a. Railway
         b. Waterway

5. The electrolytic reduction plants for extracting aluminum are highly characteristic. They consist of a series of long narrow buildings called pot rooms housing the electrolytic cells. Transverse to these at one end is the converter building where the incoming electric current is adjusted to the requirements of the process. At the other end of the pot rooms are silos for the storage of alumina. A transformer yard and high line or generator building is close to the converter building. Nearby is a plant for producing the carbon anodes. A boiler house with a tall stack and a stock pile of petroleum coke will be found at the anode plant.

6. The power requirements for the process are enormous. It takes 10 to 12 kilowatt-hours to produce a pound of aluminum. The cells in the pot rooms are arranged in series of 30 to 100, each requiring five to seven volts. The line supplying each pot room will carry 8,000 to 30,000 amperes at a pressure of 150 to 700 volts. The carbon requirement ranges between 0.6 and 0.8 pounds per pound of aluminum produced. The ore requirements are about two tons per ton of aluminum. The carbon monoxide produced in the process is used as fuel in the boiler house.

ASSEMBLY INDUSTRIES

1. There is no really simple and satisfactory method of classifying assembly industries for the photo interpreter. The usual economic classification by products is impossible, since the product of a plant can rarely be recognized from aerial photographs. Fortunately, assembly plants for mechanized vehicles, aircraft and aircraft engines, shipbuilding and ammunition are of prime interest and usually can be recognized. Other types rarely can be located without precise ground information.

2. Sometimes, industries are spoken of as "heavy" or "light." Such terms are vague and loosely applied. In general, industries requiring heavy handling equipment and manufacturing products too heavy to be built at anything but ground level are called "heavy industries." Assembly plants producing light products are called "light industries." These terms, however, include more than assembly industries; for instance, the manufacture of steel is a heavy industry and cotton spinning is a light industry. In the assembly industries a single installation may combine both "heavy" and "light" industry in a single plant.

3. Since the great majority of aerial reconnaissance photographs show only the vertical aspect of an installation, any clues to an industrial plant that can be gained from the roofs are important. Certain forms of roofs and structures on roofs are directly related to the machinery housed or the product being made. For instance, a building housing a huge traveling crane must have a roof free of interior supports that would hinder the travel of the crane. These are the principal types of roof structures that a photo interpreter should be able to recognize.

a. Monitor and ridge: a ridged roof with a central portion parallel to the ridge that is raised some distance above the roof proper for ventilation. This type of roof frequently covers furnaces, foundries and forges, and heavy handling equipment.

b. Gambrel: a ridged roof in which the sloping sides are broken by secondary ridges parallel to the central ridge. This type of roof is very common over stored materials and may be found over any type of assembly line.

c. Arched: This is self-explanatory. Such roofs can be erected with great lengths of free span. Such roofs are often found housing storage space and aircraft assembly.

d. Saw tooth: a type of "flat" roof made up of regularly spaced transverse sections, one edge of which is raised well above the "roof level." The raised edges usually face north and are glazed, admitting light. This type of roof is very common over light machine shops and light assembly plants.

e. Lean-to: a flat roof raised higher along one side than the other. Found over light assembly plants.

f. Flat: This is self-explanatory and is the most common roof met with in industrial areas.

4. Some of the important structures that may be found on roofs that may assist the photo interpreter in determining the function of the building are,

a. Sky lights: over light assembly and machine shops.
b. Fume vents: clue to a process producing toxic gases or considerable heat, such as paint shops, electro-plating, chemical manufacture, etc.
c. Dust collectors: clue to processes involving wood-working or grinding of metals, etc.
d. Condenser pipes or cooling pipes: chemical plants or ice-making plants.
e. Elevator shaft heads: light assembly.
f. Tanks: May indicate insufficient local water pressure or the tanks may contain solvents or solutions used in the process carried on in the building.

## SPECIAL ASSEMBLY PLANTS

1. Assembly plants for mechanized vehicles may be recognized by the vehicles in the storage yard awaiting delivery. Sometimes, the vehicles are moved from the immediate vicinity of the assembly plant and concentrated in yards close by major transportation facilities like wharves or freight yards. This must be borne in mind when designating the assembly plant producing the vehicles. If, in peacetime, the plant produced automotive vehicles, there may be a testing ground nearby. This will be in the form of a test track and may contain a variety of obstacles such as steep hills and mud holes. The plant will have adequate railway or waterway transportation facilities for incoming material. It will be situated with easy access to an adequate supply of labor.

2. Aircraft factories are always adjacent to an airdrome. One or more of the buildings will have a sufficient span to allow the assembly of the completed craft. Assembly plants will show much more storage space, more sub-assembly shops, and will cover much more ground than repair depots. There is usually a consider-able storage area devoted to engine cases at an assembly plant. Transportation facilities for bringing supplies must be adequate to the size of the plant. Plenty of labor must be available.

3. Aircraft engine factories may be identified by the presence of vented testblock buildings close to the assembly shops. These vents usually appear as short rectangular chimneys with unusually large cross-sections. A characteristic German test-block building contains four blocks and vents.

4. Shipyards are readily recognized by the slipways.

5. Shell loading plants are usually associated with explosives plants. Buildings in which explosives are handled are usually widely spaced, and either partially buried or surrounded by earth and concrete revetments. Shell loading buildings are usually larger than the buildings in which the powder is manufactured or stored and in which the finished shells are stored prior to shipping. Dispersed, revetted buildings are the clue to a plant handling explosives.

LUMBER AND PULP

1. The great commercial lumber producing nations are the Scandinavian nations, the United States, Russia and Canada. The interest of the photo interpreter in this industry centers on lumber mills, pulp mills and lumber yards. Under certain conditions the Corps of Engineers will be interested in standing timber of useful size.

2. Lumber mills are of two types: temporary and permanent. Temporary mills are small and portable or semi-portable. They will be found in clearings scattered through the forest. The buildings are temporary frame structures. The power usually is supplied by a small boiler house which can be recognized by its tall stack. The fuel used is wood scrap and sawdust. More rarely, these temporary mills are powered by electricity, either generated at the spot or brought in on a pole line.

3. Permanent lumber mills usually are situated on a waterway on which the logs are floated to the mill. The logs may arrive as huge chained rafts under tow or they may be brought down rivers by flood water and caught at the mill by a boom of logs and chains stretched across the river. A conveyor system carries the logs from the water to the saw mill. The sawdust is taken from the saw mill by an endless belt or a blower system. It may be delivered to a waste pile or in many plants to a cooking building. In the cooker, substances such as resins, creosote, acetic acid and crude pyroligneous acid may be produced for the chemical industry. The waste from the cooker may be used as fuel in the power plant and cooker or it may be converted into a coarse pulp for wall board, etc.

4. The saw mill proper may be recognized by its position in the entire scheme of the plant. It is the point where the logs are converted to lumber. Associated or combined with the saw mill are the engine house and power house. The latter may be recognized by its characteristic tall stack if steam is the source of power. If the mill is on a river or near a dam, the power may be supplied by a small hydro-electric plant. The cut lumber is carried from the mill to a large outdoor drying yard on narrow gauge cars. Some of the lumber may be taken to a kiln yard where it is forcibly dried by hot air as the car loads are pulled slowly through a heated tunnel. In addition to the narrow gauge system within the lumber mill there will be a standard gauge line servicing the yard. If the yard is on navigable waters there will be wharfage and heavy handling equipment for loading vessels.

5. In cities and towns, lumber and building supply yards can be recognized by the outdoor stock piles of rough lumber. Finished and first grade lumber in these yards is stored under sheds. Woodworking shops can be recognized by similar lumber storage yards. They differ from lumber yards in one detail. The buildings are equipped with dust traps and blower-conveyor systems that deliver the waste to piles some distance from the buildings. The large pipes that constitute this system emerge from the walls and roof. They are the clue to seek.

6. Pulp mills, like permanent lumber mills, are situated in places with easy access to logs. The buildings of the mill are relatively large. The logs move from storage into a chipping house, where huge rotary blades reduce the logs to a pile of wood chips. The chips are carried by a conveyor system to the digester tanks, where they are disintegrated. The mass from the digesters is transferred to the beaters where the individual wood fibers are separated and wood pulp is produced. The pulp may be made into paper. It may be drained and dried and shipped to distant plants, where it is converted to gun cotton, celluloid, rayon or similar products.

7. Pulp mills may be recognized by the presence of a great reserve of logs, either floating in booms or in stock piles; the large processing buildings; and large steam plant. They lack the drying yards, etc., of a lumber mill, the only other installation using logs in great quantity.

## CEMENT AND LIME PLANTS

1. Cement making is a relatively simple process. The raw materials are ground to a fine powder in rock mills. These powdered substances are mixed in the proper proportion and water is added to make a thin, soupy paste. This paste is called slurry. It is aged in the slurry tanks, large cylindrical vats with agitator heads that constantly stir the mass. The properly aged slurry is introduced into the upper end of the sloping rotary kilns. As it moves through the kilns, the water is driven off and the resultant mixture is roasted. The roasted material, discharged at the lower end of the kilns, is called "cinder." This may be stored or immediately ground to a fine powder. This fine powder is commercial cement. It is stored in weather-proof bins called silos.

2. Cement plants may be recognized by several characteristics.
   a. Proximity to the quarry
   b. Light railway connecting quarry and plant
   c. Light-colored roofs and surroundings due to rock and cement powder.
   d. Circular slurry tanks with agitator heads, centrally located in the flow plan.
   e. Rotary kilns with a tall stack emitting white smoke.
   f. Storage silos and packaging building.
   g. Transportation facilities - sidings, canals, etc., highways.

3. Lime plants may be confused with cement plants. There are two noticeable differences. Lime plants are less complex, consisting of a rock mill, kilns and storage and packaging buildings. Lime plants lack slurry tanks. Otherwise, they look like cement plants.

## CERAMIC PLANTS

1. Brick and tile plants are always situated close to an adequate supply of clay. They may be recognized by the following characteristics.
   a. Clay pit
   b. Curing bed - an area where the clay is worked and kept wet, appearing as a large muddy puddle.
   c. Brickyard - a group of sheds, often dilapidated, usually connected with the curing bed by means of a light railway, where the bricks are formed and dried.
   d. Rectangular kilns for "burning" the brick.
   e. Transportation facilities.
   f. Conspicuous storage yards with the products in open piles.

SHIPBUILDING YARDS*

1. Shipbuilding yards are recognized by the slipways. It is rare to find a single slipway. They are usually built in groups of at least three, and may number over 10 in a series. Sometimes, the individual ways are flanked by strong steel frames. Traveling cranes run along the top of the framework. These handle the pieces of steel being assembled into the vessel. The great majority of slipways are so placed that the completed vessel can be slid stern first into the water. Some, used for smaller vessels, launch the ship broadside into the water. The dimensions of the area within a single set of frames limit the size of the vessel that may be constructed in the slipway. Sometimes, two small vessels are built in a single slipway. When this is done, the one nearest the water is started and launched first. An experienced interpreter can estimate with considerable accuracy how nearly complete is a vessel in a slipway. If comparative photographs are available, he can estimate the launching date. A good interpreter should be able to recognize the type of vessel under construction once the deck line has been reached.

2. Slipways for submarines deserve special study by photo interpreters. These may be especially designed narrow and relatively low framed structures or may be "standard" slipways. The former are easily recognized by their size. The latter require a little study. Regular surface vessel slipways are converted for submarine building by putting in two parallel keelways, one on each side of the regular keelway, so the submarines can be built abreast. As many as six may be under construction in a single slipway.

3. Information regarding submarine construction and launchings is particularly important intelligence. Many devices are used to prevent the photo interpreter from getting a clear view of what is going on in a yard building them. The most common device is to cover the slipways with netting. This is effective to a certain extent, but a stereoscopic study of good photographs usually will reveal the outline of the vessels under construction. The enemy has realized this. In some yards, submarines are built inside huge boxes called "cocoons." These have hatchways at the top through which the parts are lowered by cranes. Usually, it is possible to determine the number of "cocoons" and how many housed vessels are under construction by carefully locating open hatches and active cranes. The interpreter cannot actually see the progress being made on each vessel and so can only report the number of active "cocoons." This is best done by numbering each cocoon and reporting signs of activity from each strip of photographs available. Since

*See Photo Industrial Study No. 7
"The Shipbuilding Industry"

most yards building submarines are covered photographically at least once a week, and often daily, the photo interpreter soon has a clear picture of activity at the yard. Some submarines are built in completely roofed slipways. Then, the photo interpreter is stymied.

4. Adjacent to every set of slipways are building and storage space for the material needed in shipbuilding. The mold loft and forming shops lie close to the slipways and are the building in which the steel plates and girders are laid out, cut and formed to pattern. Traveling cranes from the slipways pick up the produce of the shops and move it into position on the building vessel. Beyond the mold loft is the plate yard where the steel received from the rolling mills is stored until needed. Traveling cranes are found over the plate yard for carrying the pieces to the mold loft. Nearby are the buildings and shops that fabricate the engines and other machinery and fittings used in the ship. The shops always have some visible source of power, either a transformer yard or the tall stack of the boiler building.

5. The vessels are launched with little of the superstructure and interior finished. This is done to clear the limited slipway area as soon as the hulls are seaworthy. The unfinished vessels are placed in a fitting-out basin or dock. On the wharf adjacent to these are cranes and shops. These areas can be differentiated from cargo handling space by the variety of cranes, usually at least one huge hammerhead being present, and the variety of buildings. The clue to vessels that are just about ready to go to sea from fitting-out basins is the small white wake aft of them. This is caused by slowly turning over the engines to break in the bearings.

6. Submarines are finished in fitting-out docks just as any other vessel. These docks are often covered with a shed-like roof projecting out from the wharf. These are called screened-berths. Sometimes, the submarine is "blended" with the wharf with netting. Special fitting-out basins have been built near some of the principal yards producing submarines. These differ in no way from the submarine pens described in paragraph 5, and should be reported as such.

## SHIP REPAIR FACILITIES

1. Ship repair calls for two kinds of docking facilities. If the damage in no way affects the seaworthiness of the hull and the propelling and steering mechanism, the vessel can be "wet docked" and repaired at a fitting-out basin. If the damage does affect any of these, then the vessel must be "dry docked." Undamaged ships must be dry docked periodically to have their bottoms scraped and painted.

2. There are three types of dry docks. These are marine railways, graving docks and floating docks. Marine railways are used principally for small vessels. However, there are a few extant that can handle a ship up to about 10,000 tons, gross weight. This type of dock consists of an inclined railway extending from a point well above tide line to a sufficient distance into the water. On the rails is a cradle. The operation is simple. The cradle is run out to deep water and the vessel floated over it on a high tide. As the tide recedes, the vessel is berthed in the cradle and made fast. Then, powerful engines draw the cradle and its burden up onto the shore. When repairs have been accomplished, the reverse procedure is used. Cradles and hauling engines differentiate marine railways from open slipways, which they resemble.

3. Graving docks are excavated basins that have been lined throughout with masonry or concrete and are closed by a lock. Graving docks sufficiently large to handle mammoth passenger ships, battleships and aircraft carriers are not common. To use one, the basin is flooded and the lock opened. Then, the vessel is maneuvered into the basin and the lock closed. As soon as this is done, huge pumps empty the basin and leave the vessel in "dry dock." Graving docks vary little in construction. The locking may be done by a floating gate that is moved out of and into position by a tug, a swinging gate or gates, or by sliding gates that draw back into recesses. Around a graving dock are the pump house, various cranes and shops. Vessels in graving docks are often shrouded in nets to make identification difficult.

4. A floating dock is a vessel for bodily lifting a ship from the water to expose its hull for repair or cleaning. On aerial photographs these contrivances appear like huge two-sided troughs. On the walls are small traveling cranes and in them pumping machinery controls the buoyancy. The bottom and the walls are chambers that may be flooded to reduce buoyancy, so all but the uppermost parts of the walls are submerged. In this condition the ship to be lifted is maneuvered into the dock and the water is forced from the dock's flooded chambers. As these chambers are emptied, the entire structure becomes so buoyant that it lifts the ship docked in it clear of the water. When the work on the ship is finished, the procedure is reversed.

Very large vessels may be lifted by a pair of docks that are coupled together, end to end. Floating docks are rarely moved from place to place.

5. Submarine pens are a development of this war. They are huge rectangular concrete structures with roofs over 11 feet thick. They contain servicing and repair facilities for submarines. They either front on deep water or are connected with it by a guarded and roofed channel. Very little is known about the interior of these buildings. Most of what is known has come from the study of aerial photographs taken during the building of these structures and from agents in towns where they are located. The interior of the pen is divided into a number of docks separated by runways wide enough to handle small cranes and servicing trucks. Some of the docks are graving docks for repair work, while others are wet docks for fitting-out and servicing. The long time necessary to build one of these pens allows the photo interpreter ample opportunity to study its construction and estimate its capacity. Near the pen proper are found shops, power supply and transportation facilities. The shops and power supply are of massive construction for protection against bombing. Submarine pens are practically bomb-proof.

6. Structures similar to submarine pens but smaller are used by the Germans for E- and R-boats.

TRANSPORTATION

HARBORS

1. There are relatively few large, safe, natural harbors. Many of the important harbors in the world have been made so by the works of man. A good harbor must have deep water. It must have adequate protection from storms for the vessels at anchor. It must have sufficient area to accommodate safely many and large vessels. It must have a shore line that is capable of being developed as a port and for industry. Some harbors are situated on the sea, others on estuaries, a few well inland on rivers. Harbors may be recognized by an abundance of water-borne traffic and adequate port facilities ashore.

2. Not all places where ships stop to discharge their cargo have harbors. This term is applied only when the anchorage and shore are protected from the sea and storms by natural or man-made barriers. When such protection is not present, the area occupied by the vessels transacting business is called an open anchorage or roadstead.

3. Breakwaters are built to protect an open anchorage and convert it into a harbor. Breakwaters are massive stone or masonry structures to the seaward. On them are found lighthouses and range lights. Those that connect with the land are called jetties. Jetties broad enough to bear a roadway are called moles. Sometimes, the harbor side of a breakwater is built so vessels may lie alongside. Structures built along the coastline to prevent the sea from eroding the land are not breakwaters. They are sea walls.

4. Within the harbor there are few permanent structures. Lights mark dangerous shoals or anchorage areas. Large can-buoys are located in the anchorage so vessels may come to rest without dropping anchor by tying up. Bunches of piles are driven into the harbor bottom for the same purpose. These are called dolphins. They occur singly or in rows. Various types of buoys are used as navigational aids. Sometimes, the scale of a photograph is sufficiently large so these may be seen.

PORTS

1. Ports are settlements with installations for handling water-borne traffic. Ports may accommodate sea-borne, river or canal shipping. The principal port facilities are: cargo handling space, storage space, vessel servicing facilities, and transhipment facilities. The latter consist primarily of railway facilities.

2. The shore of a port contains a variety of structures. The harbor may be connected with canals or basins by means of locks. Piers project into the harbor. They are supported on piling driven into the harbor bottom. On them may be built warehouses or other necessary structures. Moles are similar but are solid construction of stone or cement and earth. They may be narrow or several hundred feet wide. Similar structures to piers and moles built parallel with the shore and united with it along one side are called wharves or quays.

3. The term "dock" is correctly applied only to the water adjacent to a mole or a pier. Slip and berth are synonyms of dock. Dock is used when the water area is narrow. Basin is used when the water area is broad. Haven and the German term "hafen" are synonymous with basin. Berthing space is anywhere that a vessel may be made fast.

4. Cargo berthing space is recognized by the presence of heavy handling equipment at the water side. In very small ports there may be no such equipment. In its stead the ships' derricks are used at these places. There may be warehouses adjacent or nearby.

5. The handling equipment is various types of hoists. The structure of these can be studied in their shadows.

a. Gantry cranes are traveling cranes on rails and consist of a hoist on a heavy cross girder supported at two points. One of these supports may be a track on the side of a warehouse.

b. Hammerhead cranes are supported at one point, about which the head can turn. The hoisting end is balanced by a cab or counterweight. The entire machine may be mounted on rails so it may be moved along the waterside.

c. Derricks have booms set at an angle to the perpendicular. These booms may be a single spar or a strongly trussed structure. The boom may be supported by a tripod or be free. The angle of the boom usually can be adjusted. The boom rotates on the base.

d. A sheer-legs is a fixed hoisting device with a leaning tripod holding the upper blocks.

6. Special types of handling equipment are found at berthing space for vessels carrying bulk cargoes. Oil is discharged and taken aboard through pipe lines. These terminate on the water side at pipe heads which are then connected with the tanks of the vessel by flexible hose. Sometimes, an oil pier juts far into the harbor over shoal water and is hardly more than a trestle supported on piling carrying the pipe line and a cat walk. If the berth is used for taking on fuel oil for the use of the vessel, it is called an oil bunkering pier, mole or wharf. Oil storage tanks are always near to a berth handling oil.

7. Coal and ore are usually unloaded by means of grab-bucket hoists. These are either Gantry or hammerhead design. In other instances, the unloading is done by endless belts of buckets that dip into the vessel's hold. Loading berths for these commodities may make use of discharge chutes from elevated bins. In the Orient, much of the loading of this class of material is done by hand using an endless stream of basket carriers. Berths handling vessels for this kind of material will always be adjacent to huge stock piles or storage bins. They are usually against wharves, sometimes, moles. Installations at which vessels receive coal for their own use are called coal bunkering piers, moles or wharves.

8. Vessels carrying loose cargoes of grain are usually discharged directly into grain elevators. This is done through large suction tubes. Grain is loaded into these vessels by chutes from the elevator. Grain elevators differ from ordinary storage bins. They are roofed. They may be rectangular or circular in plan view. They usually are taller than either horizontal dimension. Sometimes, grains are handled in sacks. For this, the handling equipment and storage space will be like that for general cargo.

9. The long shed-like buildings found on wharves, piers and moles are called warehouses. They always have easy access to some sort of transportation facility. They may flank railway sidings or may straddle a siding.

10. Small repair and servicing yards for navigational aids are found in every port. These are usually small basins. They can be recognized by the piles of reserve buoys in a yard adjacent to the dock. Piles of spar buoys have been mistaken for gun barrels!

HARBOR CRAFT

1. There are a multitude of harbor craft ranging from dories to huge floating docks. Except under special conditions, only a few of these are of interest to photo interpreters. These are ferries, tugs, lighters and barges, dredges, floating warehouses, floating cranes, and light ships.

2. Ferries are found in most busy harbors. They may be used solely for passengers or may carry vehicular or railway traffic. Ferry slips may be recognized by their structure and location. The slip itself is usually somewhat "U"-shaped. The arms of the "U" generally are made of piling and at the base is the bridge and ferry house. The bridge is hinged to the ferry house and the free end is lowered to the deck of the ferry. A Gantry-like hoist handles the position of the bridge. The approach and entry into the ferry house indicates the type of traffic carried by the ferry--railway tracks lead through the ferry house or directly onto the bridge for a train ferry, a highway for a vehicular ferry.

3. The ferries themselves vary. Passenger ferries often are launches. Vehicular ferries usually are broad-beamed and are frequently built with no definite bow and stern, the ends of the vessel being identical. The vehicles are parked in a tunnel passing lengthwise through the vessel. If the stack is amidship, the tunnel is divided by an island. If the stack is at one side, there is probably no island in the tunnel. Train ferries built along the same lines as vehicular ferries but longer are used for short hauls in relatively quiet water. Vehicular and train ferries that must be prepared for rough water and long hauls are built more like a conventional ship. On these, there is a normal bow and stern structure. The loading is done at the stern and the cargo stored in a tunnel running the length of the vessel. Ferries may be paddle- or screw-propelled.

4. Tugs are small dumpy vessels used to tow craft or to maneuver large vessels in small areas. A tug is nothing more than a floating power supply. Harbor tugs are squat and have little freeboard; ocean-going tugs are larger and have adequate protection against heavy seas. The gunwhale of a tug is protected by heavy mats and buffers. These can be seen on photographs of large enough scale. The Germans have been arming many of their tugs with a bow gun. Many tugs mount a fire hose nozzle on the roof of the pilot house. Care must be taken not to mistake this for a gun. Tugs mounting several fire hose nozzles are called fire boats.

5. Lighter is the term applied to any boat used to transfer cargo or other material from one part of the harbor to another. They may take any form and are frequently characteristic of the region where they are found. Barges and scows are special kinds of lighters.

a. Barges carry their cargo in a hold and usually are towed, but may be self-propelled. Most barges are bluntly tapered, or rounded, for and aft. Many barges are employed in canal transport. In most European harbors, these are found in special barge basins.

b. Scows are broad rectangular boats, fully decked over and carry their cargo piled on this deck. In some theaters, these are referred to as "flats." Scows are always towed.

6. A harbor situated at the mouth or a river requires continual dredging to prevent the ship channels from being clogged with silt. In some places, harbors have been enlarged by dredging. There are three general types of dredge. The most simple and least important is a grab-bucket derrick mounted on a scow. The other two are much more complicated. They are large scow-like craft with considerable superstructure, including a hoist, dredging gear, boiler and engine house. In general, they are self-propelled. One type uses a long dipper arm that carries an endless belt of buckets to the bottom of the harbor. The muck excavated by this machine is usually dumped into a hopper barge. The other type is a suction dredge. A hoist lowers a large pipe to the bottom and powerful pumps suck up mud and water. A discharge pipe from the pumps leads the mixture to either hopper barges or to the land where the water runs off and leaves the muck. The discharge pipe may be carried on pontons some distance to the shore.

7. The hopper barges used in dredging operations are so built that the bottom can be opened and the load dropped. These barges are either towed or self-propelled. They carry the dredgings to some place where it will not affect commerce. Hopper barges may be recognized by the compartmented hold and an arched catwalk running the length of the barge along the midline.

8. There are several types of floating cranes. The most simple are scows with a simple derrick or sheer-legs mounted at one end and a hoisting engine at the other. More elaborate types mount a hammerhead crane or a trussed-boom derrick and a hoisting engine. Floating cranes are towed.

9. Old hulks, ships stripped of their inner fittings, may be used as floating warehouses for explosives or noxious substances. Some are used as floating factories. Floating grain elevators are scow-like boats with a tall boiler-like structure built upon them. Suction pipes that can be lowered into a ship's hold lead to this structure. These are seen in many German harbors and are used for transhipping grain. Sometimes, fuel oil or other petroleum products are stored in special steel tank

barges that are anchored offshore.

10. Light ships sometimes are found anchored just outside of harbors. These are small staunch ships with short masts supporting a navigational beacon light. They are self-propelled.

WATERWAYS

1. Inland waterways are of three types - lakes, rivers and canals. There are relatively few lakes that constitute major waterways. There are no others that compare with the Great Lakes system of the United States and Canada. Large lakes upon which industrial cities are situated will depend to some extent upon these waters for interurban commerce. The facilities found will be like those of river ports.

2. Throughout the world, rivers are primary commercial routes. In some regions they are the only means for transportation. In each area special vessels have been developed to carry produce on these streams. The vessels may be grouped as steamers, ferries or barges.

3. The lower portion of some rivers is a long arm of the sea. This is called an estuary. Many ports are found well inland on estuaries. Some are found beyond tide-water in the river proper. When conditions allow, these ports handle ocean-going traffic. The vessels found in them will be a mixture of maritime and river types.

4. River steamers may be conventional screw-driven ships or may be propelled by stern or side paddle wheels. The screw-propelled vessels are found in deep rivers and estuaries. Paddle-wheelers are almost universal in shallow streams. Satisfactory paddle-wheel vessels can be built with very shallow draft - two or three feet - while a satisfactory screw-propelled vessel requires all of twice that draft. Paddle-wheelers are less liable to damage from snags and bars.

5. River steamers should be reported by their dimensions and type of propulsion. The extreme bow-stern dimension is called the overall length and the extreme breadth is called the beam. Paddle-wheel steamers may be recognizable by the paddle-wheel boxes or the open paddle-wheels. In cases of doubt, the wake of the vessel will identify the means of propulsion. Side-wheelers show narrow white wakes of churned water extending aft on each side from the paddle wheels, usually situated about amidships. Stern-wheelers show a broad uniform white wake extending across the entire stern. Screw-propelled vessels have a white "V" -shaped wake spreading aft from the vessel.

6. The usual type of river ferry has no true bow or stern, but can operate with either end forward. They may be screw- or paddle-propelled. The "cargo tunnel" extends through the superstructure from end to end. The ferry slips on the shore are built "U" -shaped, so vehicles can be discharged from the moored end of the vessel. Train ferries may be built similarly. The slips for these can be recognized by the railway tracks leading directly to the loading bridge. Occasionally, sea-going ferries may be found in ports some distance upstream. These vessels have a conventional bow and stern. Loading is performed at the stern where the superstructure is tunneled to admit the trains of cars.

7. Barges vary greatly. They may be open or closed. They may be rectangular scows or have bluntly formed bow and stern. They may be towed or self-propelled. They vary as much in size as they do in shape. In a detailed report they should be recorded by dimensions and means of propulsion. It is important to keep track of barge movements. In many areas, this is just as important as railway car movement.

8. Canals are artificial waterways constructed to afford inexpensive transportation or to irrigate or drain land. In low, well-watered, industrial areas, canals are very important and handle most of the heavy materials in shipment. Germany and the Lowlands have thousands of miles of such canals. These artificial waterways are easily distinguished from natural waterways by their straight lines and built-up sides. Often, they are flanked by tow paths on either or both banks.

9. Where canals join natural waterways, it may be necessary to install locks. These are chambers with watertight gates into which the barges can be floated. When this has been done, the gate is closed and the water level adjusted by pumping in water or draining it out to the level of the water in the next section. The second gate is then opened and the barge moves out into water higher or lower in level than that from which it originally came. A series of locks may carry the canal over a hill a hundred or more feet high. The location of canal locks should be noted. They and the adjacent pumping station and other machinery are excellent targets for low-level attack.

10. Along canals are basins where barges are loaded, unloaded and stored. Associated with these basins are warehouses and handling equipment. Inland industrial cities served by canals have many such basins, some large and some small.

11. Occasionally, canals are carried over narrow valleys on an aqueduct. More rarely, one canal may overpass another. Such points are extremely vulnerable and their location is important military information.



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## RAILWAYS

1. Railways are the most important means of inland transportation. The study of railway installations can be divided into two convenient parts - fixed installations and rolling stock.

### A. FIXED INSTALLATIONS

1. The British term "marshalling yard" has been applied incorrectly to any railway yard. A marshalling yard is a classification yard. These installations are used for sorting out and re-routing freight cars. The standard classification yard is composed of two sections, receiving and dispatching, connected by a "hump". The receiving section is a multiple track yard. These tracks converge upon the "hump," a low hill with a single track leading to the dispatching section. Each train in the receiving section is pushed slowly onto the "hump." At the summit of the "hump" the individual cars are cut loose and are allowed to drift by gravity into the dispatching section. Here, each track receives the cars to make up a particular train. Large classification yards may have two complete installations, "north bound and south bound," or "east bound and west bound." The entrance to the receiving section and the exit from the dispatching section are called the switching points.

2. Dock Transhipment Yards are found in port cities. These are similar to classification yards in function. They are used to sort the incoming cars and to gather together those carrying materiel to be shipped by a single vessel or steamship line. Similarly, outgoing trains are made up of cars from the various docks.

3. Servicing yards are important to the maintenance of the rolling stock. They are found in or very near all terminal cities and at division points along the route of the railway.

a. The characteristic structure found in such yards is the roundhouse. These are shops built on a circular plan and may be a full circle or only an arc around a turntable. The building is divided into stalls, each accommodating a single locomotive and equipped with a roof vent. The number of roof vents will indicate the capacity of the roundhouse. (The British often prefix the word, "roundhouse", with a fraction describing the entent of the arc, such as quarter- or half-roundhouse.) Occasionally, the "roundhouse" is not circular, but rectangular. Such are often found in France.

b. Car repair shops usually are long, low buildings astraddle one or more tracks. Cars awaiting repair or newly rebuilt are found just outside these buildings.

c. In these yards are coaling stations, large elevated bins for chuting coal into the tenders; sanding stations, similar to coaling stations but recognizable by the difference in color between coal and sand; and watering stations, large elevated tanks with a movable spout to charge the tanks of the tender. (In very mountainous country, coaling, sanding and watering stations may be found along the main line far from servicing yards.)

4. Other types of yards are found in a railway system:

a. Freight or loading yards with their associated freight stations or warehouse. In large transhipment points special types of storage places may be associated with freight yards, such as grain elevators, coal or ore bins.

b. Storage yards is the term applied to dead-end trackage for rolling stock not in use. They may be compact multiple track yards in or near a city, or may be only one or two tracks a mile or so in length paralleling the main line out in the country.

c. Station yards are the trackage used for storage, cleaning and making up passenger trains.

d. Large industrial plants may have railway facilities servicing them. These tracks are called spurs when extensive, and sidings when short. Sidings are often parallel to buildings and discharge onto loading platforms.

## B. ROLLING STOCK

1. The motive power of a train is supplied by a locomotive. These may be driven by steam, electricity, a diesel engine or a diesel-electric unit.

   a. Steam locomotives can be recognized by the shadows they cast. They can be confused with no other machine. Engines with steam up invariably show a plume of white steam.
   b. Electric locomotives are less easy to identify, but they are always associated with a system of "bridges" to carry the live overhead wires on a catenary system. The shadows cast by this electrical system are quite noticeable.
   c. The modern trend toward streamlining is making most locomotives resemble one another. However, few streamlined locomotives or diesel driven units are found outside of the United States.

2. There are six general types of cars found in trains. They are best recognized by their shadows.

   a. Passenger cars and the associated mail, express and baggage cars, are longer than the various freight cars.
   b. The majority of freight cars are box cars. These rarely can be separated on an aerial photograph from refrigerator or cattle cars. These cars are the tallest of freight cars and thus cast the longest shadow, as long as that of the locomotive or a passenger car.
   c. Hopper and gondola cars are large bins on trucks. They are used to haul bulk materials. If the material carried is affected by moisture or dirt, the cars are covered with hatches. Hopper cars have trap doors on the bottom for unloading; gondola cars are flat bottomed. These differences may be detected if the shadow detail is particularly good. This type of car is lower in profile than a box car and casts a shorter shadow.
   d. Flat cars are merely platforms on trucks used to carry large bulky objects either open, under canvas or in huge cases. Flat cars cast the shortest shadows of railway rolling stock.
   e. Tank cars are horizontal cylindrical tanks mounted on trucks. The tanks are surmounted with one to three "bell hatches" that cast a characteristic shadow. The number of hatches indicates the number of compartments into which the tank is divided.

f. The caboose is usually the last car in a freight train. Sometimes, in very long trains, another caboose may be found in the middle of the train. These cars carry the crew of the train. American cabooses have a cupola or raised cabin on the roof for observation over the top of the train. European cabooses differ from this design. Sometimes, they are a small cabin on the end of a flat car, others are in a freight car and have a railed and roofed observation platform at one end. All of these structures cast shadows that identify the car.

3. There are two kinds of special cars that need be recognized.
   a. Wrecking cars are large cranes mounted on trucks. They are often found in the yards at division points or at the scene of a wreck, repair or new construction.
   b. Artillery cars are special military vehicles. There are three types.
      (1) Railway guns are used for coastal defense or siege. They are large caliber guns mounted on specially constructed flat cars and are operated from specially constructed sidings.
      (2) Light flak cars are made from passenger or box cars. About one-third of the roof is removed and a platform mounting a light anti-aircraft gun is built in that place.
      (3) Heavy flak cars are specially constructed and resemble railway guns. They differ in that the piece is smaller and the gun does not need to be operated from a specially constructed siding.

4. Trains of cars belong to several categories.
   a. Passenger trains are composed wholly of passenger cars and the auxilliaries mentioned in paragraph 2,a.
   b. Freight trains are composed of any kind or combination of kinds of freight cars mentioned in paragraph 2,b, through 2,f.
   c. Accommodation or mixed trains are short and are operated over secondary lines. They are composed of a mixture of freight and passenger cars.
   d. Military trains resemble accommodation trains. They are made up of mixed rolling stock. They differ from accommodation trains in being long. Sometimes, the cargo on the flat cars can be identified as military equipment - guns, tanks, trucks, etc.
   e. Hospital trains are composed of passenger cars and box cars. According to International Law, the roofs of these cars bear a large red cross on a square white field.

# INDUSTRIAL CLUES

1. A good general interpreter will locate half of the individual industrial installations shown on a reconnaissance run of photographs and be able to identify accurately 10 per cent of the plants. Sometimes, there are structures so obvious that the product of the plant is immediately recognized. However, in the majority of cases this cannot be done. Many installations cannot be recognized by specialists. It is only by combining all of the available ground information with the evidence from aerial photographs that an adequate survey can be made of an industrial area. Whenever possible, the flow of material through a plant should be solved before attempting to solve the function of the plant. Pay particular attention to pipe lines in reconstructing the flow chart.

2. These clues are given primarily for the novice in industrial interpretation. They are neither complete nor all-inclusive. They do include the major features of the most important types of installations. They should be used with caution.

3. Gasometers
   - a. Coking plant
   - b. Industrial and domestic fuel
   - c. Water Gas plant
   - d. Blast furnaces
   - e. Nitrogen-fixation
   - f. Synthetic fuel plant
   - g. Synthetic rubber plant
4. Dispersed tank farm
   - a. Petroleum storage
   - b. Petroleum refinery
   - c. Synthetic motor fuel plant
5. Small clusters of tanks
   - a. Chemical plant
   - b. Edible oil storage
   - c. Paint and varnish plants
   - d. Domestic fuel oil distribution
   - e. Naval stores

5A. "Slurry" tanks
   - a. Cement works.
   - b. Bauxite refining (alumina production)
   - c. Sewage disposal (sub-surface tanks)

6. Tall slender cylinders
   - a. Chemical plant
   - b. Petroleum refinery
7. Tall stacks
   - a. Power plant
   - b. Rotary kilns
   - c. Coking plant
   - d. Metallurgical furnaces
   - e. Chemical plants (usually slender)

8. Large squat towers, usually steaming
    a. Continental-type cooling towers, usually associated with metallurgical and chemical industries and thermal power plants.
9. Large Transformer Yards
    a. Commercial power supply
    b. Aluminum reduction
    c. Electric furnaces
        (1) Carbide production
        (2) Crucible steel
    d. Hydrogen plant (gasometers)
        (1) Nitrogen-fixation
        (2) Synthetic motor fuel
10. Monitor-type roof
    a. Heavy industry
        (1) Metal-working plants
        (2) Heavy assembly plants
    b. Chemical industry
        (1) Electrolytic cell houses
11. Arched roof
    a. Broad rectangular building
        (1) Aircraft assembly
    b. Narrow rectangular building
        (1) Storage
12. Saw-tooth roof
    a. Machine shops
    b. Industries requiring much light and ventilation.
13. Ventilated roof
    a. Chemical industries
    b. Paints and varnishes
    c. Bessemer converters
14. White-dusted roofs
    a. Flour mills
    b. Cement plants
    c. Lime plants
    d. Bauxite refining plant
    e. Bessemer converters (local dusting)
    f. Foundries and forges (local dusting)
15. Stock piles of dark material
    a. Domestic coal yards
    b. Railway servicing yards
    c. Coaling docks
    d. Coking plant
    e. Metal smelters
    f. Thermal power plants
    g. Synthetic oil and rubber plants

16. Installations near open pit mines or quarries.
    a. Cement or lime kilns
    b. Brick works
    c. Any coal-consuming industry
17. Plants with complex system of overhead pipes.
    a. Chemical plants
    b. Petroleum plants
    c. Coking plants
18. Small, low, rectangular buildings with large, short, vent chimneys.
    a. Engine test blocks
19. Large, low buildings with combined transverse and longitudinal roof pattern.
    a. Buildings broad and pattern alternating
        (1) Rolling mills
    b. Buildings narrow, transverse section across several longitudinal section
        (1) Aluminum reduction
20. Heavy handling equipment
    a. Heavy industry
21. Revetted buildings
    a. Explosive plants, ammunition loading and dumps.
    b. Hydrogen purification
    c. Synthetic fuel plants
22. Large masses of logs in rivers, lakes or bays
    a. Lumber mill
    b. Paper pulp mill

INDUSTRIAL CAMOUFLAGE

1. Camouflage is a method for denying information to the enemy. This is accomplished by disguising the object with paint, netting, garnish or any combination of these. Paint and texturing materials are used to blend the object with the surrounding terrain by simulating it in tone and pattern. Netting is used to obscure the outline of the object and eliminate tell-tale shadows . Garnish is used to simulate the texture of the environment of an object.

2. Industrial plants are so large and usually so well known that they cannot be hidden successfully from all observation. Stereoscopic study of aerial photographs is the most satisfactory method for breaking through camouflage. Installations that are hidden to visual observation are revealed in this manner. The enemy knows this as well as we do. The purpose, therefore, of industrial camouflage is to hide an installation from visual observation for sufficiently long to prevent the bombardier from making a satisfactory run on the target. If this is accomplished, the camoufleur has succeeded. The task of the Photo Intelligence Officer is to circumvent this by revealing the true nature of the camouflaged area and referring it to easily recognized land marks.

3. Paint is employed in various ways. The roofs of buildings may be painted with a uniform neutral color so they blend with the general surroundings. Roads or paths may be painted across these roofs to heighten the effect. When this is done, these "roads" may continue to ground level via slopes of netting to join with real roads and paths. In more complicated camouflage, large flat roofs may be painted with a dappled pattern to represent vegetation or even with outlines of small buildings so the area appears to be a settlement of small houses. While all of this may be deceiving in a single photograph or to visual observation, the lack of depth and incongruity of natural and painted shadows is at once recognizable under the stereoscope. Shadows or their lack are often the key to a camouflaged area.

4. In very elaborate camouflage small dummy buildings and artificial trees may be erected on very large flat roofs or on top of huge areas covered by netting. These are less easy to recognize than simple painted jobs. However, a careful study will usually reveal the artificiality of the installation. Artificial trees are often recognized by comparing them with known real trees in the area. It is not uncommon to discover that the artificial trees are in summer foliage in autumn or winter when the real trees are leafless!

5. Netting is used very frequently as a drape to break up the regular shadows cast by buildings. Nets may also be spread over a large expanse of roof that is broken up into a characteristic pattern. A similar use of netting is found over tank farms. A frequent use for netting is to obliterate land marks close to an important factory. Many German plants are situated on waterways and have their own barge basin or canal. These are often covered with netting to prevent them from being used by bombardiers. They are effective both day and night, since in addition to hiding the waterway in daylight, they prevent reflection by the surface of the water of starlight or moonlight at night. The most extensive installation of this type covered the entire Binnen Alster in Hamburg.

6. The conformation of characteristic basins may be altered by floating rafts upon them. These rarely cover the entire basin, usually just enough to alter its shape, and particularly, its reflection at night.

7. A method of concealment that is being used extensively is a blanket of low hanging smoke. This is generated in various types of machines, most of which, when seen on aerial photographs, resemble oil drums. These may be placed anywhere - along roads, on wharves, on barges or vessels - so long as the prevailing wind drifts the smoke over the area to be hidden. A system of smoke generators can easily blanket an entire town or harbor. It is often possible to locate smoke generators once they have been used by the fan-shaped smudges left to the lee of them.

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# BASIC PHOTO INTERPRETATION VISUAL ORIENTATION TEST

These three problems will indicate your facility in orienting ground and air views of the same objects. The ability to transpose different angles of view is one of the components of photo interpretation skill. It is greatly increased by practice on problems like these.

The first rule is: Do not jump to conclusions.

The second is: Do not be discouraged if you fail one or more. Very few persons get them all right the first try.

Speed does not count.

PLEASE DO NOT "THINK OUT LOUD" WHILE YOU ARE DOING THESE PROBLEMS.

## PROBLEM A

(1) Lay an acetate sheet over vertical photo #21. Using the grease pencil, mark where the four corners fall and draw a circle around the Jefferson Memorial. Then write your name on the edge of the acetate.

(2) Compare ground photograph A with the vertical to determine the point from which the ground photograph was taken. Turn the vertical around as much as you wish, keeping the acetate in register with it. When you think you know where the ground photo was taken from, mark an X on the acetate over that point.

(3) Now decide how much of the ground photograph is included in the vertical. Draw a line on the acetate where each edge of the ground photo cuts across the vertical. These lines will form a V indicating the angle of view.

Note: If you wish to erase, rub with tissue.

(4) When this acetate is ready to hand in, put this set of photos away and take out the next set.

## PROBLEM B (Same Procedure as A)

(1) Lay a clean acetate over vertical photo # 34, mark the corners, and draw a line through the marginal data. (White writing on one edge) Write your name.

(2) Compare photo B with the vertical and mark X on the acetate over the point from which you think B was taken.

(3) Draw on the acetate the two lines showing the edges of the angle of view. Be sure the acetate hasn't slipped around!

(4) When finished put this acetate aside ready to hand in, and take out Photo C and the large mosaic.

PROBLEM C (Essentially same procedure)

(1) Place acetate over general center of the target Mosaic. Write your name and draw 3 lines over the 3 bridges shown, with a tick mark at each end to show where the river bank cuts.

(2) This time, draw the angle of the view on the acetate first. The two lines indicating the edges of Photo C will converge on a point.

(3) Mark X at the apex of the angle of view; this is the spot from which the photo was taken.

PLEASE DO NOT DISCUSS PROBLEMS WHILE OTHERS ARE WORKING

Answers will be given when acetates are in.

Did you write your name on all acetates?

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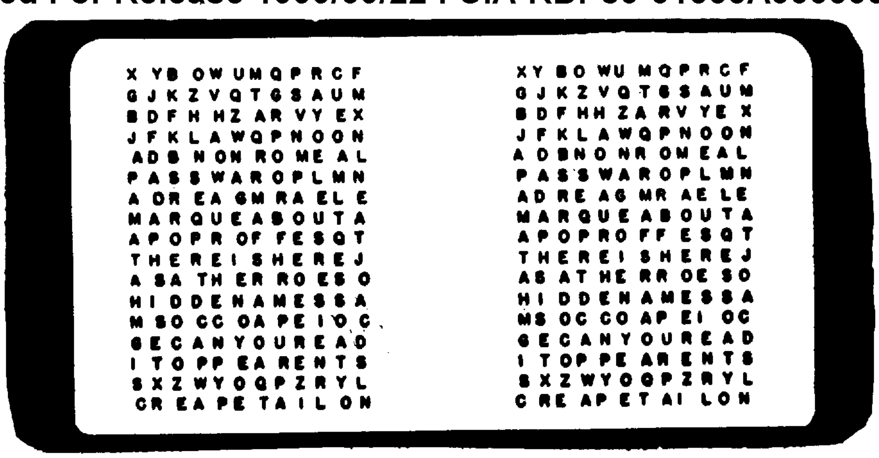


What is the hidden message?

PI 368

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BASIC PHOTO INTERPRETATION TEST FOR STEREO VISION

These problems will indicate your ease or difficulty in seeing in Three-D. Everyone who has reasonably adequate vision in both eyes can "see stereo." There is no trick or special gift. Persons with unequal visual acuity or different focal lengths may have a little difficulty at first in re-learning to use both eyes. The most important instruction is - RELAX.

Then place your stereoscope on sheet A over stereogram #3 and bring your head down until the lenses are right in front of your eyes. (If you wear reading glasses, keep them on.) Your forehead may rest on the 'scope.

Relax your eyes as though you were looking through the table at your feet.

The two images will float together and merge. If they don't merge fairly soon, make sure one 'scope is straight across stereogram # 3 and the center of the scope is over the center dividing line.

Now write your name on the 5 X 8 card and try the problems.

PROBLEM A - (Sheet A)

(1) Does any one of the three stereograms look "different" to you? If so mark on your card the number of the one which does. PLEASE DO NOT THINK OUT LOUD

PROBLEM B (Sheet B Man-made structures)

(1) Stereogram 4. Which is higher, point A or point B? Write on your card the letter of the highest point.

(2) Stereogram 5. Points A, B, C, D are annotated. Write them on the card in order of height, the highest first.

(3) Stereogram 6. Is A or B higher? Write the letter of the higher point on the card.

Note: If any of the points look about equal, indicate it like this on your card: A=B.

PROBLEM C (Sheet C - Terrain)

(1) Stereogram 7: Indicate on the card the point which you think is definitely higher, A or B.

(2) Stereogram 8: Same as 7
(3) Stereogram 9: Same as 7
(4) Stereogram 10: Same as 7

If the images blur, look up, relax and clean the 'scope lenses.

PROBLEM D (Sheet D - movement)

(1) This stereogram of the Union Station yards shows you the effect of moving objects. Since the two photos were then a few seconds apart, trains in motion will appear in different places. By blinking each eye alternately the moving train will appear to "jump." Count the number of trains (and single engines) you can see in motion and write the answer on the card. If everything starts to jump around, get a clear fix on a building or the turn table and then look back at the trains. Just for fun, look at moving cars and pedestrians but do not count.

PLEASE DO NOT DISCOVER THINGS OUT LOUD WHILE OTHERS ARE WORKING!

Answers will be discussed after cards are handed in. Is your name on your card?

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# BASIC PHOTO INTERPRETATION RECOGNITION TEST

This test will indicate your facility in recognizing objects on average quality, medium scale, air photographs. No one is expected to answer all the questions. Do not be depressed if you miss most of them. The photograph will be shown again toward the end of the course. You will find yourself able to recognize much more. Answers will be discussed then.

The photograph is a German reconnaissance photograph of a Russian industrial district, taken during World War II.

Speed is not essential. Take as long as you wish within reason.

INSTRUCTIONS:

Place photo with clock-face at your lower left.

See that the acetate overlay is firmly clipped in place.

With the grease pencil, write your name in upper right corner of overlay. Write neatly or it will smear.

Draw the outlines of the clock and the black box in the upper left corner on the overlay to mark where the overlay belongs on the photograph.

Now look over the whole list of questions BEFORE STARTING TO ANSWER THEM. There is an important note at the end.

QUESTIONS:

Can you recognize these things? If so, mark the required symbol with your grease pencil on the overlay over the item you see.

<u>Warning</u>: Not all the items asked for actually appear on the photograph. If you think a certain type of installation, for instance, an aircraft plant, is <u>not</u> on the photograph, mark "NO" after the question on this test sheet. Correct "NO" answers count double.

MAKE YOUR ANNOTATIONS NEAT AND PRECISE.

1) Mark "RR" over 3 railroad lines, like this:

2) Mark "M" over 2 motor roads, like this:

3) Mark "W" over a body of water (not a drainage ditch).

4) Mark "R" over a residential section (blocks of homes or apartments).

5) Mark "B" [illegible]

6) Mark "WH" over groups of warehouse buildings.

7) Mark "L" over a locomotive.

8) Draw the outlines of 3 industries.

9) Draw an arrow pointing in the direction you think is north (Good guess counts double).

10) Mark "AA" over an anti-aircraft gun battery.

11) Mark "ZZ" over trenches or ground fortifications.

12) Under your name, write how many miles or feet you think there are from one side of the photograph to the other. (Good guess counts triple)

13) Mark "Y" over a railroad yard (many sidings).

14) Draw a circle around a group of tanks.

15) If you think they are petroleum tanks, write "P" in the circle

16) Mark with an "H" anything you see that confirms the general date of the photo. (Written in the clock) This may not apply to certain photos.

17) Mark "XX" over a war-damaged building.

18) Mark "E" over an electric power station.

19) Mark "S" over an open storage pile (Gravel, ore, coal, etc.).

20) Mark "A/F" over an airfield

21) Write "Metal" over a machine shop or engineering works.

22) Write "PR" over a petroleum refinery.

23) Write "AL" over an alumina or aluminum manufacturing plant.

24) Write "Coke" over a coke-oven.

25) Write "Brick" over a brick or ceramics factory.

26) Write "Ammo" over an ammo plant or dump.

27) Write "Chem." over a chemical plant.

28) Write "Radio" over a radio station.

29) Write "Trans." over a transformer yard or electric sub station.

30) Write "A/C" over an aircraft or aeroengine plant.

31) Draw a triangle around an electric power pylon.

32) Write "canal" over a navigable canal (not a drainage ditch.)

IMPORTANT: If there is a technical term that confuses you in the above questions, underline it and write "??" in front of the question. Please help us on this, so we can make our questions clear.

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BASIC PHOTO INTERPRETATION SCALE PROBLEMS

These problems do not involve stereo vision. A stereo pair is included in each problem for your interest and to aid you in checking the edges of the objects to be measured.

Please write your name and the answers on a 5 X 8 card. Do your figuring on the work sheets. Answers will be discussed after cards are handed in.

PROBLEM A

Find the diameter of the base of the Jefferson Memorial.

Materials: Vertical photos #22 and #23
USGS map of Washington
Scale .001"

Procedure: (1) Look at the lower margin of your map, find the scale, and write this figure at the top of your work paper. Fold the map to show the Jefferson Memorial area.

(2) Inspect photo #23 and orient it with the map.

(3) Using the .001" scale, measure on the map the distance between two points shown on the photo. Example: End-to-end of small lagoon at north of Basin. Multiply this by the denominator of the scale. This is the ground distance between these points.

(4) Using the .001" scale measure the distance between the same points on the photo. This is the photo distance between these points.

(5) Divide the photo distance into the ground distance. The dividend is the denominator of the photo scale. If your arithmetic was correct you can find any ground distance by multiplying its photo distance by this figure.

(6) Before measuring the monument, check for photo distortion by taking another measurement at an angle to the first. Example: Distance between bridge [illegible] of Memorial and nearest point of land across Basin. Multiply this by the map scale denominator to find ground distance. Measure the same distance on the photo and divide it into the ground distance. Your second photo scale should be only slightly different. Take the mean between.

(7) Now measure the monument across the center of the dome to the outside edges of the white steps. Look at it in stereo to check the edges if you wish, but use photo #23 to measure. (Why?) Multiply this measurement by the mean photo scale. This is the diameter in feet of the stylobate (base) of the Monument. Write this figure on the 5 X 8 card.

<u>TROUBLE NOTES</u>:

(1) If you can't see the small divisions on the scale, try using one lense of the 'scope (it magnifies). To see better, use the little thread counter. It has a scale on the bottom.

(2) If your figures don't come out right, it is due to one of these causes:

a. Mistake in reading scale. Check all measurements.

b. Simple error in dividing or multiplying. Check.

c. Decimal point trouble. The smallest divisions on the scale are thousandths of a foot. (.001') The largest are tenths (1')

d. Did you use the centimeter side of the scale for one or more measurements? (If you use it throughout, you will come out with the right distance in <u>meters</u>.)

e. Map error. You may have measured from a point which has changed between the photo and the map, or which was drawn incorrectly on the map. Shorelines vary. Road edges are only approximate.

f. Taking too small a map measurement. In general the smaller the distance the greater the error. (This is why the monument cannot be measured directly before finding the scale).

g. Failure to measure the same points on map-photo.

<u>PROBLEM B</u>

How long are the sides of the Pentagon?

Materials: Vertical photos #566 and 567
USGS map of Washington
Scale

<u>Procedure</u>: (Same as in Problem A)

(1) Orient photograph #566 in relation to the map. Write the scale of the map on your working sheet.

(2) Make two measurements on the map across the center at the

area shown in the photo. Examples: Center to center of various clover-leafs or road intersections. Multiply these measurements by the scale to find the ground distances.

(3) Measure the same distances on the photo and divide each measurement into the respective ground distance. Take the mean as the photo scale.

(4) Measure an outer side of the Pentagon and multiply by the photo scale. Write this lengthfor the Pentagon's sides on the 5 X 8 card.

PROBLEM C

Identify the plane taking off from Bolling Field. (Same procedure as A & B)

Materials: Photos 515, 516
Air Target Mosaic of Washington
Scale .001"

(1) Find the scale of the Target Mosaic and write it on your work sheet.

(2) Measure two distances on the Mosaic and find the ground distance. (i.e. = multiply by the scale.) Examples: Runways

(3) Measure the same distances on photo #515 and find the photo scale.

(4) Measure the plane seen taking off and find the actual span and length. (i.e. multiply by photo scale) Note: Why will Photo #515 yield more accurate figures than #516?

(5) Identify the plane from the list below and write the name on the answer card.

| DESIGNATION | SPAN | LENGTH | NO. MOTORS |
|---|---|---|---|
| B-17 | 103' 10" | 74' 9" | 4 |
| B-29 | 141' 2" | 99' | 4 |
| B-36 | 230' | 162' 6" | 6 |
| B-47 | 116' | 107' 6" | Jet |
| B-50 | 141' 2" | 99' | 4 |
| C-46 | 108' | 76' 4" | 2 |
| C-47 | 95' | 63' 9" | 2 |
| C-54 | 117' 6" | 93' 5" | 4 |
| C-74 | 173' 4" | 123' 4" | 4 |
| C-124 | 173' 4" | 127' 1" | 4 |
| C-97 | 141' 4" | 110' 4" | 4 |
| C-121 | 123 | 95' 4" | 4 |
| R-60 | 189' 1" | 156' 1" | 4 |

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PHOTO INTERPRETATION QUIZ ON COKE, IRON AND STEEL

To be used with photograph No. D-15 from the 325th Recon. Wing. Ind. PI Manual. Reichswerke Herman Goering at Hallendorf, Germany, Sep. 1941

Please disregard top stereo pair until the last question.

1. How many blast furnaces are there?

2. How many gas holders are there?

3. How many smokestacks serve the coke ovens?

4. How many cross-over mains leave the coke ovens?

5. Would you say the coke ovens are in operation?

6. Is the coke-oven byproducts plant to the left or right of the ovens?

9. How many Bessemer converters are at this plant?

10. How many open hearth furnaces are there here?

11. Are the soaking pits at the top or bottom of the rolling mills?

12. Would you say the rolling mills are in operation?

13. What do the large pipelines running thruout the plant carry?

14. Are transformers visible near the power plant?

15. What significance can you see in the lower right quarter of the photo?

17. Can you guess at the function of the related plant shown in the top stereo pair?

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D/GP Basic Course

These packets consist of selected sets of German Air Force photos of USSR installations. In some cases only one or two industries are shown, in others there are industrial complexes. Each set contains an assortment of types of photo cover showing the installation in large and small scale, at different times, and where possible in oblique view, under snow, and other interesting aspects. The general nature of the packet is indicated as largely metallurgical, chemical, etc., thus allowing the student to select a packet suited to his interests and time.

The packet may be taken to his office for study and practice in identifying and understanding a target area through the use of photography alone. To assist him, he may borrow photo industrial recognition manuals from D/GP. According to his interest and skill, he may make an intensive analysis of some aspect of the target, or range over the area identifying as many as possible of the objects shown.

In all cases the student should establish the approximate scale of at least one photography, and measure some distance or object shown thereon. Since the altitude of these photographs is unknown, the student may establish scale either by measuring some object whose size is approximately known, or by taking a distance from a map of the area. Each case will present an individual problem. Results will be reviewed by the instructor on the basis of comprehension and intelligent attack by the student.

Secondly, the student should in all cases identify the area by geographic coordinates. This may be taken from any convenient standard map.

The student's report should consist of a written sheet identifying the photography studied by sortie (mission) number, print number and date where possible, and giving the coordinates and scale. In the body of the report he will state whatever information he has extracted from the photos, either as a brief general statement or a detailed description, according to his interest, skill and available time. For convenience, grease pencil annotations may be made directly on the photos and the written remarks keyed to them. Example: 'The boiler house at point"A" is ___ metres X ___ metres, and was probably not operational in 1943 because of bomb damage.

Each report will be judged as an intelligence performance in the context of the individual student's aims. The aim of D/GP is to help intelligence researchers to acquire a technique and stimulate interest.

When the student has completed his study of the packet he may check his findings against the appropriate A/F Target Mosaic (available from CIA Map Library, Graphics Register or D/GP). Further questions can then be discussed with D/GP instructors.

As many packets as desired may be drawn consecutively.

PHOTO INDUSTRIAL TRAINING PACKETS MUST BE SIGNED FOR ON H/R AND SHOULD BE RETURNED WITH ALL PHOTOS INTACT AND RE-USABLE AFTER ANNOTATIONS ARE CLEANED OFF.

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D/GP TRAINING COURSE NO. 1-I IN THE
INTERPRETATION OF PHOTOGRAPHY FOR INTELLIGENCE PURPOSES

NAME: ______________________ DATE: ______________

AGE: ____ VISION: Normal ___ Corrected ___

INSTRUCTOR SHOULD ASK STUDENTS TO INDICATE WHETHER VISION IS APPROXIMATELY EQUAL IN BOTH EYES, OR WHETHER ONE EYE IS DOMINANT. ("STRONGER")

LOCATION: Office ____ Division ____ Branch ____

TELEPHONE EXTENSION: __________

ACADEMIC
BACKGROUND: University Specialization ______________
Degree(s) ______ ______ ______

MILITARY EXPERIENCE:

PRESENT SPECIALIZATION:

NO. YEARS EXPERIENCE AT CIA: ____

EXPERIENCE IN PHOTOGRAPHIC INTELLIGENCE:

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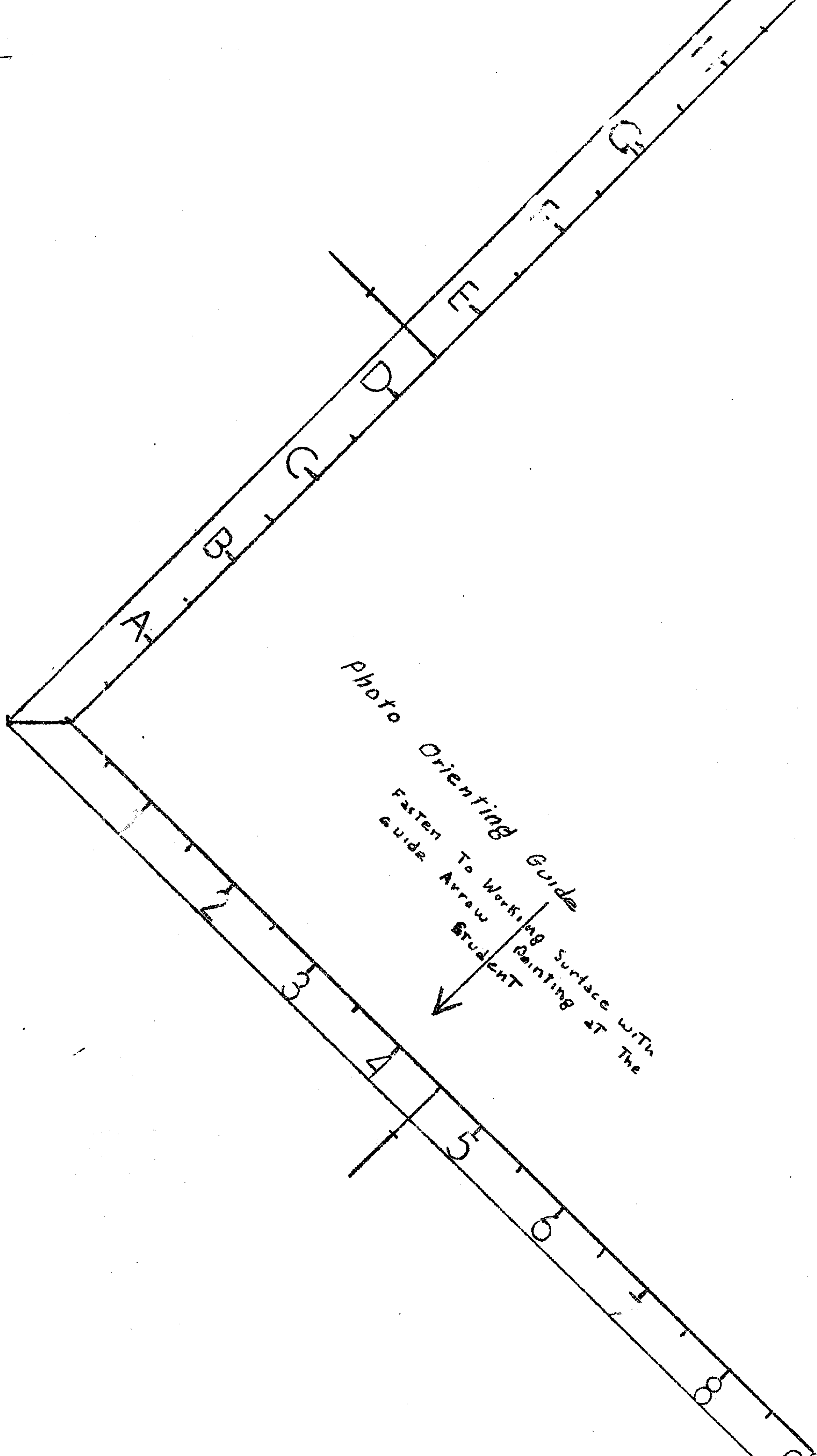
STAFF RECORDS:

TAB


A
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E
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9
Photo Orienting Guide
Fasten To Working Surface with Guide Arrow Pointing at The Student

TAB

# A SYSTEMATIC ANALYSIS OF SOME FACTORS AFFECTING PHOTOGRAPHIC INTERPRETATION

Robert N. Colwell

## INTRODUCTION

In recent years it has become traditional in our Society to devote a portion of each annual meeting to a panel discussion on photo interpretation. Ordinarily each speaker on such a program has been given a few minutes in which to deliver a rapid-fire report on that particular phase of photo interpretation with which he is primarily concerned. That these panel discussions have been quite successful is perhaps best evidenced by the consistently large attendance which they have commanded. But even good programs usually are criticized by those with insatiably high standards. One criticism of our past photo interpretation programs has been that the full significance of each speaker's report could not be appreciated because little was done to integrate the individual reports into an over-all analysis of the photo interpretation problem.

The foregoing comment was passed along to Mr. Charles Coleman, chairman of this year's photo interpretation panel, at the time when he invited the speaker, as chairman of our Society's photo interpretation committee, to help plan and participate in the present program. By thus committing a major tactical error, the speaker found himself saddled with the assignment of attempting to present at this meeting a systematic analysis of the major factors affecting photographic interpretation. It obviously is with some misgivings that he undertakes this assignment, particularly in the presence of such an august group as we have here assembled today. To add to his misgivings, it is planned, at the conclusion of his remarks, to ask various experts within the audience to comment upon certain aspects of his analysis and to submit such information as they may have relative to the analysis. Although this course of action should prove to be very enlightening and interesting for all of us, the present speaker's enthusiasm for the plan is dampened somewhat by the realization that, by the time he has concluded his own remarks, he probably will have placed himself in the vulnerable position of being "the man most likely to be enlightened."

It should be emphasized that the present speaker, in the course of his remarks, will be drawing largely upon facts or beliefs which have previously been brought to light by various individuals present in this audience. Whatever claim to originality he might hold for this paper must rest in large measure upon his attempt to integrate these facts in terms of their significance to the over-all interpretation problem.

Unless otherwise stated, the discussion which follows will pertain primarily to vertical aerial photographs, while not necessarily excluding its applicability to other types of photos as well.

Photographic interpretation has been defined as the act of examining the photographic images of objects for the purpose of identifying the objects and deducing their significance. This definition suggests that systematic analysis of factors affecting photographic interpretation might logically be divided into two major areas, within each of which we have already amassed great clouds of information: (1) Factors governing the quality of photographic images; and (2) Factors governing the perception and interpretation of photographic images.

Let us therefore fasten our seatbelts and fly directly into the first of these cloud masses, seeding it with a few orderly thou'hts as we go. If our seeding experiment works, we may clear away some of the clouds and get a better look at the remaining ones.

## FACTORS GOVERNING THE QUALITY OF PHOTOGRAPHIC IMAGES

By way of introducing the first of several concepts that may draw fire in our subsequent discussion period, factors governing the quality of photographic images will be grouped simply into four categories: (A) Tone and color characteristics, (B) Image sharpness, (C) Stereoscopic parallax, and (D) Other factors.

### (A) TONE AND COLOR CHARACTERISTICS OF PHOTOGRAPHIC IMAGES

The photographic tone or color of an object is directly dependent upon four main factors, each of which is presentable as a function of the wave length of light:

(1) light reflectivity of the object photographed

(2) light sensitivity of the film employed

(3) light scattering by atmospheric haze

(4) light transmission by the filter used.

Other factors such as amount of exposure, nature of the light source, and laboratory techniques and materials used in processing and printing likewise exert important influences on photographic tone or color. However, when these factors are in suitable balance, as is usually the case, the four factors just listed remain as very critical ones governing photographic tone.

Of the four factors, two are essentially beyond the control of the photographer, namely the light reflectivity of the objects being photographed and the light scattering by atmospheric haze. Therefore, when taking black-and-white photography, the photographer must first take cognizance of the limitations imposed by these two factors; then he must arrive at a combination of the other two factors (photographic film and filter) which will produce suitable photographic tone characteristics. Figures 1 and 2* provide an example of how this may be done intelligently, instead of on a trial-and-error basis.

When employing color photography, still a third of these four critical factors passes largely out of the control of the photographer, namely the photographic filter, to be used, for if more than a slight color correction filter is employed the resulting photographic images will exhibit decidedly abnormal color characteristics. It is true that in special instances abnormal photographic color characteristics are acceptable or perhaps even preferred, as in the case of camouflage detection. However, for general interpretation purposes, the value of color photography appears to be directly proportional to the faithfulness with which it registers the true color characteristics of the objects photographed.

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*Note: All figures mentioned here will be shown as lantern slides and discussed.

Restrictions as to the type of filter that can be used with color film, combined with problems of atmospheric haze, have thus far made it virtually impossible to obtain aerial color photography at altitudes greater than a few thousand feet, which would be as useful for general interpretation purposes as black-and-white photography taken from the same altitudes. Both the value and limitations of aerial color photography in its present form are illustrated in Figure 3, and will be alluded to again in a subsequent section of this paper.

(B) IMAGE SHARPNESS

Two terms currently in use for describing image sharpness are "resolution" and "acutance." Since the term "acutance" was introduced into the literature only a short time ago by Higgins and Jones (1952) of Eastman Research Laboratories, it is perhaps well to indicate how it differs from the more commonly used term, "resolution." The resolution obtained on an aerial photograph usually is expressed as resolving power in lines per millimeter, corresponding to the spacing of the smallest individually-discernible stripes on a photograph of a resolution target. Until recently this value has also been considered an adequate measure of image sharpness and therefore of the suitability of photographic images for interpretation purposes.

The lack of correlation between resolving power and sharpness is well illustrated by the prints in Fig. 4A and 4B, which are part of the aforementioned work of Higgins and Jones which led them to development of the new term "acutance," presently to be defined. In this experiment, the same negative was printed on two experimental positive materials to give the best-matched tone possible. The positive material used in printing Fig. 4A has a maximum resolving power in excess of 230 lines per millimeter, while the positive material used in printing Fig. 4B has a maximum resolving power of only 130 lines per millimeter. It is obvious that even though the material used in making Fig. 4B has a very much lower resolving power, the prospects for general interpretation are much greater in B than in A. In an effort to measure this important difference in the suitability of photographic images for interpretation purposes, Higgins and Jones have developed the concept of "acutance" as a measure of image sharpness. Perhaps because of the paucity of our language it is difficult to define acutance in a few words. It can be defined mathematically as the product, $(\overline{G_x^2}) \cdot (DS)$ as explained in the following paragraph and by reference to Figure 5.

When a photographic material is exposed to light while partially shielded by a knife edge in contact with the emulsion (as shown schematically at the top of Figure 5 ), the developed image does not end abruptly at the knife edge but encroaches upon the shielded area and has a diffuse boundary. (Higgins and Jones, 1952) A microdensitometer trace across this knife-edge image typically yields a curve such as that labelled "D" in the lower part of Figure 5. The ordinates for this curve represent density and the abscissas, distance on the negative in microns. The steepness of the knife-edge gradient at any part on the curve, such as C, obviously is expressed in terms of the increase in density, $\Delta$ D, which accompanies a unit increase in distance on the negative, $\Delta$ X. The flattest tone gradient detectable by the human eye is known to be that giving a change of approximately 0.005 density units per micron. All points on curve D of Figure 5 which are to the left of point A are outside this limit and hence appear isotonic; the same is true for all points to the right of point B. Alternately stated the distance from $X_a$ to $X_b$ is that over which the visually detectable knife-edge gradient is spread on the negative. The average gradient, $\overline{G_x}$, between A and B is independent of the image density distribution between these two points. Thus curves D, E, and F of Fig. 5 all give the same value for $\overline{G_x}$. However, the human eye perceives 3 different sensations of image sharpness from these 3 curves since the cones of the eye, in scanning back and forth across this area, translate minute density gradients, $\Delta D/\Delta x$, to log illuminance gradients, $\Delta \log B/\Delta x$, in the image formed on the retina of the eye. One means of expressing quantitatively the differences in sharpness of curves D, E, and F is through use of the mean square value $\overline{G_x^2}$ obtained in each case by (a) squaring the various values for $\Delta D/\Delta x$ (based on 0.005 unit increments of D, this being the threshold value for detectability), (b) determining the total sum of these individually squared values and (c) dividing this sum by the total number of values. In terms of the calculus this relationship is expressed by the equation

$$\overline{G_x^2} = \int_A^B \frac{\left(\frac{dD}{dx}\right)^2 \cdot (dx)}{X_b - X_a} .$$

Since the impression of sharpness in the tone-edge gradient also would seem to vary directly with the total tone range, DS, traversed by the gradient, Higgins and Jones have tentatively decided upon the expression, $\left(\overline{G_x^2}\right) \cdot (DS)$ as a physical measure of image sharpness, and have termed the values thus obtained "acutance values."

The foregoing rather technical discussion could not be justified in a paper such as this were it not for the fact that the physical measurements for acutance (a) are readily made and (b) are highly significant in terms of the interpretation of photographic images since they constitute a far better index of image sharpness than do any other objective values known.

Another striking example of the inadequacy of the term "resolution" to define the suitability of a photographic image for interpretation purposes is provided by a comparison of Fig. 6A and 6B. Despite its lower resolving power, Fig. 6B is superior to Fig. 6A because the former was focused to give maximum acutance while the latter was focused to give maximum resolving power (as determined with a resolution target). Similarly it may be stated that Fig. 4B is superior to Fig. 4A because the former provides higher acutance in this particular case even though the latter has nearly twice the resolving power (in terms of lines per millimeter).* Higgins and Jones assert that "all data taken to date indicate that acutance can be used to predict the sharpness of pictures made with different photographic materials." (2)

It should not be inferred from the preceding paragraph that resolving power is no longer a value worth determining. The fact must not be overlooked that the human eye, under a given set of viewing conditions, can resolve a certain number of lines per millimeter in a photographic image. Resolving power, therefore, may still be a potentially limiting factor in that various components of the photographic system (including lenses, films and papers) should be of such quality as to provide resolving power characteristics in the image well above the threshold values detectable by the human eye. In this connection it is pertinent to note that the unaided human eye, when viewing a resolution target at the normal reading distance of 12 to 14 inches can resolve a maximum of about ten black and white lines per millimeter. This value is of course increased commensurately when the eye is aided by magnification, as when looking through a lens stereoscope. Since the average aerial photographic print of good quality yields resolution in the neighborhood of 15 to 20 lines per millimeter, the potentially limiting nature of resolution for study of photos through a magnifying stereoscope is readily apparent. At the same time it must be remembered that resolving power, measured in the conventional manner, does not constitute as good a measure as acutance, for expressing the ultimate sharpness of photographic detail which can be well resolved by the human eye. Mr. Higgins summarized this point rather well when he stated informally to the speaker that "resolution measures a certain limiting threshold of image sharpness, whereas acutance measures a sort of super-threshold of image sharpness."

The factors most critical in determining the image sharpness obtainable with any particular photographic system are: (1) Aberrations of the lens system, (2) Focus of the lens system, (3) Image motions at the instant of exposure, and (4) Characteristics of the photographic materials. Each of these factors will now be discussed briefly.

(1) Aberrations of the lens system

The term "aberration" relates to any defects of an optical image caused by imperfections of the lens system. The several types of aberrations are classified as astigmatism, chromatic aberration, spherical aberration, coma, curvature of field and lens distortion. Since each of these types is well discussed and illustrated in many texts (including the Manual of Photogrammetry, 1952), no further details will be given here. However, it is important to realize that even minor aberrations in an aerial camera's lens system may so seriously detract from the image sharpness obtainable. This fact has recently been emphasized by Zernike (1951) who states that "every single aberration causes a deterioration proportional to its square, independent of the others."

One type of lens aberration is sufficiently pertinent in relation to certain types of photo interpretation to merit emphasis, namely chromatic aberration. As the term "chromatic" implies, different colors of light may come to focus at different distances from the lens, as in the case of longitudinal chromatic aberration; different colors of light also may produce different magnifications, as in the case of lateral chromatic aberration. Most aerial camera lenses are color-corrected to minimize these types of aberration on the assumption that conventional panchromatic minus-blue photography will be taken with them. It therefore is not surprising if poor image sharpness results from the use of such lenses for infrared photography or other special types that are sometimes used to accentuate certain tone differences. In such cases the lens system is being used for wave lengths of light vastly different than those for which it has been color corrected.

It is conceivable that the importance of being able to detect and recognize on aerial photos objects having unique reflectance characteristics might assume such great importance in the future as to justify the use of special camera lens systems which have been color-corrected for the particular wave lengths of light desired in the photographic exposures.

(2) Focus of the lens system

Recent experiments at Boston University (Macdonald, 1951) and elsewhere indicate that there is no single setting of distance between film plate and lens which will bring all images at a given distance from the camera into equally sharp focus, regardless of their sizes. Briefly stated, in these experiments the optimum focus for any object was found to be that setting at which approximately 80 per cent of the total light passing through the lens system from the object was concentrated within the so-called "blur-circle" image of the object. Since the size of the blur circle varies with the size of the object photographed, the optimum focal setting also varies accordingly, as diagrammed in Figure 8. For the usual multi-purpose photography this finding is a difficult one to exploit, as the photo interpreter desires good image sharpness in objects which vary widely in size. However, if we again assume that some particular type of photo interpretation involving objects of uniform size may be of such importance as to merit its own special photographic mission (and numerous examples of this already have occurred), then we may also assume that adjustment of the focal setting for such special purposes is not an unreasonable requirement. The following are examples of types of photo interpretation in which such a requirement might exist: (1) the making of traffic surveys in which automobiles of relatively uniform size are to be detected and enumerated; (2) the making of personnel counts at a public gathering or of troops on a battlefield; (3) the making of a fish or wildlife census from photography on which the particular population to be detected and enumerated usually is remarkably uniform in size; and (4) the making of log counts in a sawmill pond or tree counts and related measurements in an even-aged stand of timber. Assuming in the case of each of these objects that vertical photography were to be flown at a specified scale, the size of the "blur circle" produced by the images of the objects at that scale could be readily calculated and the focus adjusted accordingly.

The enthusiasm for obtaining an optimum focal setting for the specific purpose here under consideration should not blind one to certain realities. Specifically such uncontrollable factors as atmospheric pressure, temperature, plane vibration, etc. may cause the focus of an aerial camera to be altered in flight, regardless of the great accuracy with which it may previously have been set. Ignoring such realities one might strive to develop a camera lens which would provide a very sharp Resolution/Focal Setting curve such as that labelled "A" in Fig. 9. In the light of such realities, however, he might better strive to develop a lens which would provide a broad bell-shaped curve, such as that labelled "B" in the same figure. It is obvious that such a lens exhibits acceptably sharp focus over a much greater range of focal settings and hence would give acceptable results more consistently.

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(5) Image Motions at the Instant of Exposure.

There are several factors which may cause the optical image of an object, formed at the focal plane of an aerial camera, to exhibit motions relative to the photographic film during the instant of exposure (Macdonald, 1952). That such motions may seriously detract from the image sharpness obtained on the resulting photography is evidenced by the fact that the in-the-air performance of an aerial camera system frequently provides less than half the image sharpness (and sometimes less than 1/5 the image sharpness) obtainable in the laboratory using the same equipment.

The primary types of image motion may be grouped roughly as follows:

(a) Linear aircraft motions caused by the translational (forward) motion of the photographic aircraft.

These motions are only in the direction of flight and can be largely eliminated through employment of so-called "image motion compensation" magazines, which cause the film to move along the focal plane during the period of exposure at a rate commensurate with forward motion of the image itself (McNeil, 1951).

(b) Angular Aircraft Motions (Roll, Pitch and Yaw).

These motions, occurring at the instant of exposure, obviously can cause serious blur of the image. The act of levelling a camera for each individual exposure, in the presence of these motions, likewise may cause image blur.

(c) Vibrational Motions of the Airframe, Camera Mount, Camera, or Camera Elements.

With the advent of jet photographic aircraft and their seemingly smooth riding qualities the conclusion was prematurely reached by some that vibrational motions would no longer be of serious consequence to the photographer. Unfortunately, such is not the case, for although vibrations of long-wave length are much reduced in jet aircraft (as evidenced by their smoother riding qualities) vibrations of short-wave length remain very serious. Means of dampening vibrational motions of the photographic system assume increased importance as camera focal length increases, because of the increased lens-to-film distance over which such vibrations dan be amplified.

Figure 10, from Dr. Macdonald's studies, provides an indication of both the relative and absolute seriousness of the various image motion components just discussed.

At present most authorities consider that the cumulative effect of various image motions constitutes the factor which most limits image sharpness. Certainly this conclusion is indicated when it is considered that, under laboratory testing conditions, aerial photographic lenses, films, and papers commonly are capable of yielding resolutions of at least 75 to 100 lines per millimeter, whereas the actual aerial photographs obtained with such equipment rarely provide resolution exceeding 15-20 lines per millimeter. This is true even when both "air boil" disturbances immediately beneath the photographic aircraft and atmospheric haze disturbances between camera and object are favorably low; these facts serve still further to isolate image motions of the types just discussed as the primary causes of poor imagery.

(4) Characteristics of the Photographic Materials

Since much of the discussion at the beginning of this section pertained of necessity to photographic materials, little additional need be said on the subject at this point. However we would do well to re-examine the product "$(\overline{G_x^2})$. (DS)" illustrated in Figure 5, which is used to measure acutance. The discussion thus far under the heading of "Image Sharpness" relates primarily to the steepness of the photographic tone "edge gradient" and therefore is applicable primarily to the "$\overline{G_x^2}$" half of the acutance factor. Since the remaining half, "DS", expresses the total tone range traversed by the photographic edge gradient, this half also merits consideration in our discussion of image sharpness.

Obviously, the magnitude of the factor, "DS", is governed by the over-all tone contrast between the photographic image of an object and its background. Thus, in concluding this discussion of factors affecting image sharpness we are led back to our initial discussion of factors affecting photographic tone. In this way we again come to recognize the importance of selecting a suitable film-filter combination for each photographic mission. An attempt will be made later in this paper to indicate, from the photo interpreter's standpoint, the relative importance of photographic tone, per se, on the one hand, and photographic tone as a factor governing image sharpness, on the other

The importance of chemical solutions used in developing and fixing photographic images should not be overlooked. These solutions obviously must be of the proper chemical composition, temperature, and state of agitation at the time of their use if latent photographic images are to be converted into interpretable ones.

Possibilities for the use of certain special techniques (such as overexposure and underdevelopment to bring out the details of objects in shaded areas) merit special consideration.

Glossy ferrotyped contact prints are preferred over all other types by many photo interpreters, but care must be exercised when interpreting such prints that the light source is so positioned as to eliminate glare from the glossy surface.

One objective in photographic printing is to spread the grey scale of tones over as large a number of visible steps as possible. With this in mind experiments currently are being conducted (Nelson, 1952) on perfection of (1) a "negative analyser" which will scan each negative electronically to determine its density range, (2) a variable contrast photographic paper adaptable to a wide range of negative densities, and (3) a variable contrast printer which, in conjunction with items (1) and (2) will give each negative or portion thereof the proper exposure at the time of printing.

Possibilities for the use of transparencies rather than the conventional opaque prints and of full color images rather than monochromatic ones will be discussed in a subsequent section on the viewing of photographic images.

(C) STEREOSCOPIC PARALLAX

Parallax is defined as the apparent displacement of the position of a body with respect to a reference point or system caused by a shift in the point of observation. All of us recognize that if the photo interpreter is to perceive objects three dimensionally, and thereby make a much more complete interpretation than would otherwise be possible, he must be provided with photographic images having proper stereoscopic parallax characteristics. Accordingly a critical, but brief analysis of factors governing the stereoscopic parallax characteristics of photographic images would seem to be within the province of this article. Figure 11 attempts to summarize these factors in diagrammatic fashion.

As indicated in Figure 11, the form of the parallax equation with which we are perhaps most familiar is as follows:

$$h = \frac{H \cdot dP}{P + dP}$$

Since we are interested here in analysing the factors governing stereoscopic parallax, dP, it is helpful to transpose the above equation to the following form:

$$dP = \frac{P \cdot h}{H - h}$$

When the parallax equation is rewritten in this second form, the following factors are seen to govern the stereoscopic parallax characteristics of an object, and in the fashion indicated:

(1) P, the absolute parallax of the base of the object, commonly referred to as the stereo base. Since this factor appears only in the numerator of our second equation, the magnitude of dP is seen to be directly proportional to the magnitude of P.

(2) H, the height of the camera lens above the base of the object. Since this factor appears only in the denominator of our second equation, the magnitude of dP is seen to be inversely proportional to the magnitude of H.

(3) h, the height of the object. This factor appears in both numerator and denominator. However its effect in the numerator, as a multiplicand, far exceeds its effect in the denominator as a subtrahend. Accordingly the magnitude of dP is directly proportional to the magnitude of h.

The importance of our clearly understanding the above relationships is accentuated when we recognize that: (a) the photo interpreter ordinarily does not desire images which exhibit maximum stereoscopic parallax because he cannot then fuse the images of relatively tall objects throughout their entire extent; therefore he cannot adequately appreciate their three-dimensional form; (b) neither does the photo interpreter ordinarily desire the minimum of stereoscopic parallax, as this would cause all but the tallest objects to appear two-dimensional. Since there is thus seen to be an optimum parallax range, it would seem appropriate to analyse the above factors quite carefully before a photo mission is flown to make sure that the photography as contemplated will exhibit the desired stereoscopic parallax characteristics. Again looking forward to the time when photographic missions will be flown to satisfy specific objectives, we can appreciate the potential importance of such an analysis in detecting and interpreting objects of rather uniform height, such as automobiles, or personnel, or even-aged timber stands; the same may be true when the primary objective is to determine depths of water, gradients of beaches, or steepness of landforms within specified ranges.

It will be noted that neither camera focal length nor photographic scale is listed in the foregoing analysis as one of the factors directly affecting stereoscopic parallax. However, the indirect effects of focal length and scale, through their influence on one or more of the factors just listed must not be overlooked. Because of certain problems in camera design, film manufacture, film processing, and print viewing, the "format" or negative size of an aerial camera does not increase in proportion to focal length, beyond a certain size range. As a result, cameras of very long focal length have a greatly reduced base/height (P/H) ratio (Aschenbrenner, 1950). Consequently photographic images at a given scale exhibit greatly reduced parallax when taken with cameras of long focal length. This, in turn, means that despite the large scale of photography the height or third dimension of all but the tallest objects becomes imperceptible on long focal length photography flown at the high altitudes for which such cameras are designed. For pinpoint reconnaissance purposes this difficulty is adequately overcome by the taking of convergent stereo pairs, as diagrammed in Figure 12. For the more general situation in which extensive areas are to be interpreted no ready solution to this problem presents itself. The importance of this problem in relation to the interpretation of objects lacking great height becomes apparent when we consider that the smallest differential parallax which an interpreter can detect is from 2 to 4 times smaller than the smallest two-dimensional detail he can detect (Salzman, 1949 ; Aschenbrenner, 1950). Failure to obtain normal stereoscopic parallax in aerial photography may therefore impose the requirement for a two-fold to four-fold increase in photographic scale to compensate for this deficiency. This point will be covered more fully in a later section.

(D) OTHER FACTORS GOVERNING THE QUALITY OF PHOTOGRAPHIC IMAGES

Most of the factors not mentioned heretofore which govern the quality of photographic images can be grouped under three major headings as follows: (1) Time of photography, (2) Type of photography and (3) Scale of photography.

(1) Time of Photography

Insofar as the diurnal aspects of aerial photography are concerned there are obvious advantages in most cases to photography having minimum shadow length. With this in mind it is commonly stipulated that the sun must be at least 3½ hours above the horizon, at the time of photography. Alternatively it may be stated that the time of photography must be within, say, two hours of local noon. Such specifications obviously should be tailored to the latitude of the area being photographed, the time of year, and the type of interpretation being performed.

Seasonal aspect is of obvious importance in relation to the appearance of foliage and to the presence of snow, ice or water which might obscure pertinent ground detail on the photographs (Figure 13). Requirements are so variable in this respect as to defy the making of broad generalizations.

The weather aspects conventionally desired for obtaining the best photographic image dictate a time for photography when there are cloudless days with virtually no smoke or haze. However there have been instances reported in which photography flown beneath a high overcast proved superior to that flown on bright sunny days, both for multiplex mapping and for many types of photographic interpretation. The principal advantage of such photography seems to be that it provides much better detail in shaded areas. Although a longer exposure obviously is required in order to obtain such photography, image blur has been found to be negligible for photography flown at a scale of 1/20,000.

Finally, the sequential aspects discernible from comparative interpretation of photographs taken of the same area at successive time intervals may be of great value for certain types of interpretation. At one extreme may be the time interval of a few seconds between successive exposures of the same photographic run, from which the rate of movement of vehicles or other objects may be determined; at the other extreme may be the time interval of several years, from which the rate of erosion, plant succession or other relatively slow-moving phenomena can be observed.

(2) Type of Photography

Mr. Robert Frost published an excellent article in the June 1953 issue of Photogrammetric Engineering in which he recognized four so-called "types" of photography: (a) Vertical photo coverage, (b) Trimetrogen photography, (c) Continuous strip photography and (d) Composite (or multiple-lens) photography. Since Mr. Frost discussed the relative merits of these four types, the present speaker wishes merely to commend his article to the audience. Because of ambiguity in the term "type of photography" as here used, any suggestions for a more suitable term would be gladly entertained during the discussion period which follows this paper.

(3) Scale of Photography

Photographic scale is meaningful to the photo interpreter only when considered in terms of resolution. As previously stated resolution measures a certain limiting threshold as to the image sharpness required to recognize objects. It is obvious that there will be a certain threshold value (or narrow range of values) for resolution on any given aerial photograph at which the photo interpreter will barely be able to recognize an object from its photographic image. This threshold resolution value probably is best expressed in terms of "lines per object" required for recognition. The value of such an expression is that it serves to highlight the inter-relationship between photographic scale and photographic resolution. Thus it is apparent from such an expression that, within the recognition threshold range, the chances for recognition of an object on aerial photographs may be increased by either (a) increasing the scale at a given resolution or (b) improving the resolution at a given scale.

In concluding this section, reference is again made to Mr. Frost's article in which information of general interest is given as to the relative merits of photographic scales ranging from 1/2000 to 1/60,000.

Having thus concluded our discussion of factors governing the quality of photographic images, let us now direct our attention to factors governing the perception and interpretation of those images.

FACTORS GOVERNING THE PERCEPTION AND INTERPRETATION OF PHOTOGRAPHIC IMAGES

In certain phases of the ensuing discussion it will be helpful to keep clearly in mind the difference between "detection" and "recognition" of photographic images. The term "detection" as here used merely implies the act of becoming aware of the existence of an object, independent of its actual identity, through discernment of its photographic image. The term "recognition", however, implies the establishment of an object's actual identity through a study of its photographic image.

In order that objects can be detected on aerial photographs, their photographic images need merely exhibit suitable tone or color characteristics; specifically, there must be a sufficient tone or color difference between the images and their surroundings to inform the photo interpreter that there is a discontinuity of the background tone or color at those points on the photo where the images appear.

In order that objects can be recognized on aerial photographs, however, their photographic images must be sufficiently sharp to inform the photo interpreter as to the configuration of the objects.

If, for example, on black-and-white photography the objects photographed consist of a mixture of light-toned squares and circles superimposed upon a dark background, there will be a "detection threshold" at which there is just enough tone stimulus for an interpreter to detect the presence of these objects without being able to recognize which are squares and which are circles. There will also be a "recognition threshold" at which there is just enough discernible as to the configuration of the objects to permit their recognition as squares or circles by the photo interpreter.

Probabilities for both the detection and recognition of an object on photographs can be conveniently analyzed in terms of its so-called "edge gradient" characteristics. The term "edge gradient" refers to the abruptness of tone or color change between the edge of a photographic image and its background. Thus, for an object to be detected the absolute tone or color range traversed along the edge gradient between that object and its background should be sufficiently great to be detectable by the photo interpreter. For the object to be recognized (e.g., as a square or circle) the steepness of the edge gradient must be sufficiently great, as a result of good resolution and acutance characteristics, to give the image of that object a recognizably sharp outline.

Photographic tone or color, on the one hand, and image sharpness on the other, obviously are interrelated factors insofar as the detection and recognition of objects are concerned, since they are the primary factors governing edge gradient characteristics (Macdonald, 1951). Thus, as image sharpness increases, edge gradients are steepened so that the tone or color contrast required to detect any given object decreases; conversely, as tone or color contrast increases, edge gradients again are steepened so that the image sharpness required to recognize any given object decreases. Experiments on black-and-white photography have shown that despite the interplay of these two factors, tone is the primary factor governing the detection of objects, while image sharpness is the primary factor governing their recognition. In the case of color photography however, it is well known that color differences not only facilitate the detection of objects but are commonly of great value in the recognition of objects as well.

While the foregoing analysis appears to be valid for the examination of individual photographs, an additional and extremely important factor, namely stereoscopic parallax, enters into the interpretation of stereoscopic photography as will be mentioned in a subsequent section.

Factors governing the perception and interpretation of photographic images will now be analysed under the following three headings: (A) Characteristics of the photo interpreter; (B) Characteristics of the photo interpreter's equipment and (C) Techniques employed by the photo interpreter.

(A) CHARACTERISTICS OF THE PHOTO INTERPRETER

(1) Visual Acuity

In an excellent treatment of the factors in human vision applicable to photogrammetry and photo interpretation, Salzman (1949) defines visual acuity as "the ability to see separately and unblurred the details of the visual object as those details are made smaller and closer together." In the same article, he defines "visual sensitivity" as "the ability of the eye to respond to (illumination) stimuli." In attempting to follow through with our announced plan of making a systematic analysis, let us now consider the photo interpreter's visual acuity in terms of the previously-discussed photo image characteristics, namely; (a) tone and color, (b) image sharpness and (c) stereoscopic parallax. It is to be hoped that in so doing we will acquire a keener insight as to the importance of each of these factors in the interpretation of photographs.

(a) Discernment of photographic tone and color

Some of the most significant research on visual acuity is that relating to tone contrast thresholds of the human eye (Blackwell, 1946). In Blackwell's experiments, trained observers were placed at one end of a 60-foot room and an illuminated observation screen was placed at the other end. A spot of light or "stimulus" was then projected onto the screen in any one of eight possible positions. If the observer were able to detect the stimulus, he indicated in which of the 8 positions on the screen the stimulus had been projected. By decreasing the contrast between the stimulus and the screen, it was possible to decrease the probability of detecting the stimulus. The "threshold contrast" thus determined was defined as that contrast at which the observer could detect the stimulus with a probability of 50%, due allowance having been made for chance success. Actually it was found that an observer did not feel confident of having seen a stimulus unless the contrast were such that the level of probability of detection exceeded 90%.

Some of the results obtained from these tests, involving nearly 2 million observations are summarized by the average probability curve shown in Figure 14.

The following points are of particular interest to the photo interpreter who is confronted with the similar problem of detecting small objects by virtue of tone contrast between them and their background:

Within the threshold range, a rather slight increase in the relative contrast greatly increases the probability of detection. This fact serves to accentuate the potential importance of selecting a photographic film-filter combination which will increase, even though only slightly, the tone contrast between an object and its background. (Means for doing this intelligently, instead of on a trial and error basis have already been discussed.) This finding also indicates the possible advantage of viewing color transparencies successively through various filters each of which may increase tone contrast on a certain part of the photo depending upon the spectral reflectance characteristics there of the objects to be interpreted and of their environment.*

Stimuli darker than the observation screen have a detection threshold approximately 20% lower than that of stimuli which are lighter than the observation screen. This fact would seem to indicate that objects of relatively low reflectance, in that part of the spectrum photographed, can be more readily detected on photographic <u>positives</u>, whereas objects of high reflectance can be more readily detected on photographic <u>negatives</u>.

Additional factors, not covered in Blackwell's experiments, but pertinent to this discussion are as follows:

The human eye can detect approximately 100 steps (tone edge gradients) on the grey scale when viewing <u>opaque photographic prints</u>; on the other hand it can detect up to 300 steps on <u>photographic transparencies</u>. This indicates clearly a potential superiority of transparencies over opaque prints for the aerial photo detection of small objects.

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* It might seem that the filter offering best tone differentiation for the viewing of a color transparency might be predicted either (a) from a reflectance spectrum analysis of the object and of its background or (b) from a transmission spectrum analysis of the same elements made directly from color transparencies. As evidenced by the report of Tarkington (1952), however, the latter method is preferable because the color transparencies of objects will rarely, if ever, exhibit transmission spectra identical with the reflectance spectra of the objects themselves.

able to distinguish approximately 200,000 different steps on the color scale (i.e., 200,000 different combinations of hue, value and chroma) as compared with the 100 to 300 steps discernible on a grey scale. This would seem to indicate very greatly increased opportunities, through use of color photography, for detecting the edges of photographic images. These tests also show that it is is harder to distinguish between two <u>shades</u> of color than it is to distinguish between two <u>luminosities</u>. This fact would seem to offer further support for the suggested viewing of color transparencies through filters capable of exploiting luminosity differences (Colwell, 1950; O'Neill, 1952).

The human eye exhibits appreciably more visual responsiveness to brightness changes in the <u>light</u> end of the grey scale than in the <u>dark</u> end (see Figure 15). This fact can be exploited when viewing transparencies simply by proper adjustment of the light source.

The human eye exhibits less visual acuity toward light in the blue and red ends of the spectrum than to green and yellow-green light in the central portion of the spectrum (Shlaer, Smith and Chase, 1942). The magnitude of this factor is indicated in Figure 16. In view of the shape of this curve consideration might well be given to the use of green or yellow-green illuminants when viewing either opaque prints or transparencies.

(b) Discernment of resolved detail (image sharpness)

The work of Helmholtz (1909), Polyak (1941), Bryam (1944) and others on the physiology and photochemistry of the eye, together with the vision testing experiments of Blackwell (1946) and Jones and Higgins (1947) indicate that there are only a relatively few cones, situated around the center or "fovea centralis" of the eye, which are functional to an appreciable degree in the discernment of minute photographic detail. (See Figure 17.) When viewing a photograph these cones are stimulated by a rapidly changing illuminance. This is explained by the fact that, even during attempted fixation on a point in the visual field, the eyeball is not absolutely stationary. Instead, it is subject to a multi-directional vibratory motion of relatively small amplitudes ($\pm$ 1.2 minutes) and high frequencies (25 cycles per second) of the type indicated in Figure 18.

The importance of this phenomenon in terms of discernment of photographic detail can be illustrated by a single example: In order for the photo interpreter to discern a circular photographic image, such as that of a tree crown having moderate tone contrast with its background, nearly 300 cones must be activated by illuminance changes along the edge of the image. If there were absolute fixation of the eyeball, therefore, the smallest circular object of this tone contrast which the eye could detect would be one whose periphery passed through approximately 300 cones when imaged on the retina of the eye. However, because of the eyeball's vibratory motion the necessary 300 cones are activated by an image so small that it does not entirely cover a group of 4 cones at any given instant. In light of the foregoing discussion it would seem quite plausible to attribute at least part of the differences in visual acuity of "sharp-sighted" and "dull-sighted" photo interpreters to differences in the vibratory characteristics of their eyes. Loss of visual acuity as a result of fatigue might be partially explained on a similar basis.

Recent experiments reported orally to the writer by Higgins and Jones (1952) show that visual acuity of the human eye is considerably greater when the diameter of the pupil is approximately 4 mm than when it is of either larger or smaller diameter (see Figure 19). This would seem to indicate that when very detailed interpretation is to be performed the over-all luminosity of the photographic print or transparency should be adjusted so as to cause the pupil to dilate to this optimum diameter. (Compare with Fig. 15)

The number of cones in the human eye which must be activated by illuminance changes in order to detect a photographic edge gradient will, of course, vary with the amount of contrast between an image and its background. Thus Macdonald (1951) found that in the presence of very high relative contrast 73 lines per millimeter could be resolved by the human eye, whereas with very low relative contrast less than 5 lines per millimeter could be resolved (see Figure 20). Macdonald (1951) also plotted image contrast as a function of focal setting with detail size as a parameter, as shown previously in Figure 8. It will be noted that as detail size increases there is a shift to the right of the focal setting which gives maximum tone contrast. This effect can no doubt be considered as corollary with the earlier discussion in which it was stated that the lens focusing should be such that approximately 50% of the light would be focused within the blur circle.

Figure 20 is excellent for illustrating the previously-mentioned relationship between tone and image sharpness from the photo interpreter's standpoint. As indicated in this figure any object such as "A", which is to the right of the contrast threshold curve, is not perceptible to the human eye. It can be made perceptible in either of two ways: (1) by increasing the relative contrast between "A" and its background, thereby moving "A" upward until it crosses the contrast threshold curve, or (2) by increasing the image sharpness (discernible lines per object), thereby moving "A" to the left until it crosses the contrast threshold curve. In the speaker's opinion the significance of this figure in terms of our analysis of factors affecting photographic interpretation can scarcely be over-emphasized. Here, in the results of an actual series of tests, would seem to lie ample justification for our rather lengthy analysis of factors governing photographic tone and image sharpness. The conscientious photo interpreter who always is seeking means of extracting more information from photos, must be vitally interested in all means by which uninterpretable images such as "A" can be transposed to the left side of the curve (Figure 20).

While Fig. 20 is excellent for summarizing relationships between photographic tone and image sharpness, it does not summarize the third dimension of our analysis, namely stereoscopic parallax. Accordingly, let us next briefly investigate visual acuity in relation to stereoscopic parallax.

(c) Discernment of stereoscopic parallax (binocular acuity)

At first thought it might seem that the smallest differential parallax detectable by a photo interpreter would correspond to the smallest photo detail he is able to resolve,-- or, (in the words of the professionals) that "stereoscopic acuity" would correspond to "vernier acuity." However, actual tests have shown, as previously mentioned, that the smallest differential parallax which a person can detect is from $\frac{1}{2}$ to $\frac{1}{4}$ the size of the smallest photo detail he can resolve (Aschenbrenner, 1950). This seems logical when we consider that by exercising stereoscopic vision the observer perceives one entire group of detail (representing a particular object or element) against another group of detail, representing the background. Assuming that this concept of a detail group applies to objects which are so small as to be barely at the detection threshold, stereoscopic visual acuity emerges as perhaps the most critical human factor governing the photo interpreter's ability to detect small objects on aerial photos. Additional research on this problem is to be encouraged.

Independent of the parallax factor stereoscopic or binocular study of aerial photos may produce at least two other beneficial increases in visual acuity: (1) A photo interpreter's binocular acuity is reportedly equal to the sum of his two monocular acuities. This is attributable at least in part to the fact that binocular luminosities are higher than monocular ones as reported by Hartman (1933) and Ryan (1940); (2) Imperfections of the single photo image attributable to its graininess may not be apparent when stereo mates are examined binocularly. Statistically it is not probable that such imperfections would occur at exactly corresponding points on both members of the stereo pair. Except where they do occur in corresponding positions, each photo image will tend to reinforce its mate when viewed binocularly, thereby providing sharper over-all detail than could be perceived from examination of either image alone.* (A common example of this binocular

* In this connection the reader is urged to study Fig. 7 stereo-

reinforcement concept is in the ability to perceive the white center line of a highway even at scales as small as 1/20,000 when viewing both photos of a stereo pair simultaneously.)

(2) Mental Acuity

As has just been indicated, the successful photo interpreter must first of all possess sufficiently high visual acuity to perceive clearly the photographic images which is attempting to interpret. Of equal importance, he also must possess sufficiently high mental acuity to comprehend the significance of these images once he has perceived them.

The mental acuity of a photo interpreter, in the sense here used, depends upon a number of factors including his background of training and experience, his powers of observation and imagination, and his judgment. The present speaker's views relative to each of these factors have been expressed at considerable length in Chapter 12 of our Society's Manual of Photogrammetry" (1952) and therefore will not be repeated here.

A photo interpreter's mental acuity, like his visual acuity, may decrease appreciably under the influence of fatigue. Obviously it is his acuity at the time the photo interpretation is being performed, rather than his potential acuity, that governs the quality of his interpretations. Some significant work recently has been performed in Sweden on the fatigue of photo interpreters in relation to the reliability of certain of their photogrammetric determinations. The only other information known to the speaker relative to this highly important matter must be categorized simply as "folklore" gleaned from various P.I. bullsessions in which various individuals narrated their "combat experiences" with a stereoscope. Judging from the highly divergent accounts thus received, additional research relative to this subject is sorely needed.

The working posture of a photo interpreter in relation to his acuity would also seem to merit further investigation. Virtually all photo interpretation is done today with the interpreter's neck bowed and his head assuming an angle of nearly $90^\circ$ relative to his torso. It is considered probable that such posture severely restricts the flow of blood through the interpreter's brain, thereby impairing his acuity. One possible solution to this difficulty, through design of an improved stereoscope permitting more suitable posture will be mentioned under the section dealing with a photo interpreter's equipment. In the same section mention also will be made of the advantages and limitations of photo interpretation keys as an attempt to compensate for deficiencies in the photo interpreter's mental acuity.

(B) CHARACTERISTICS OF THE PHOTO INTERPRETER'S EQUIPMENT

(1) The Projector-Type Stereoscope


[illegible] the various factors discussed in the immediately preceding section on characteristics of the photo interpreter, the ideal type of stereoscopic viewing equipment might well embody each of the features listed below. Practical limitations to the field use of such equipment are, of course, recognized.

(a) Facility for viewing transparencies by transmitted light, in lieu of the present system of viewing opaque prints by reflected light. Theoretically this would provide a threefold increase in the number of edge gradients discernible, as previously stated, and would be particularly beneficial for the detecti[illegible] of objects in shaded areas requiring greatly increased illumination (See Figure 15).

(b) Facility for projecting the stereo image onto a frosted screen (from a point behind the screen) in such a way that by changing the distance between the projector and the screen the scale of the projected image could be varied between wide limits. This feature should permit the photo interpreter (1) to view the entire stereo model at once when attempting to determine the over-all topographic or environmental situation within the area to be interpreted, and (2) to view any item of detail on the stereo model at the maximum enlargement permitted by sharpness of the image.

(c) Use of a polaroid projection system rather than a dichroic or anaglyph type. The polaroid system is superior in that (1) it permits the viewing of color transparencies in full color; (2) it permits the viewing of color transparencies through various filters, each of which is designed to increase the tone contrast between certain objects and their background depending upon their combination of reflectance characteristics (Figures 1 and 2); and (3) it tends to eliminate "retinal rivalry" which frequently prevents extraction of the ultimate in photographic detail when the anaglyph principle is used. Although polarization of the projected image causes a reduction of approximately 50% in image intensity (when the light source remains constant) it ordinarily will be possible to increase the intensity of the light source to a point at which this factor is not limiting.

(d) Facility for independently adjusting the light intensity from either element of the stereo projector. Thus, if the image received by the interpreter's left eye were appreciably less bright than that received by his right eye, he could increase the intensity of illumination of the duller image until both left and right eye images were perceived equally well. This should permit the photo interpreter to achieve the maximum stereoscopic effect. Furthermore, such a lighting arrangement would permit the interpreter to increase the light intensity through both projectors simultaneously when he wished to perceive the maximum detail within shadows or in otherwise underexposed portions of the transparency (See Figure 15). It would also permit him to adjust the light intensity striking either eye, to such a level as would give the desired pupil dilation for the type of interpretation being performed. This [illegible]

(e) Facility for effecting a tone reversal between an image and its background so that each image to be detected would be darker than its background, instead of lighter. This would increase the probability of detection by 10-20%, according to Blackwell, as previously mentioned. While some television screens permit the ready conversion from negative to positive transparency it may not be possible to incorporate such a feature in a stereoscope which embodies all other features here described.

(f) Facility for permitting the interpreter to search the stereo model in a systematic fashion (e.g., through the use of a grid system) and some means of blanking out each grid square once it has been searched. The logical dimensions for such a grid may be indicated by Figure 17 in which it is seen that for an image to be detected the interpreter's line of sight must fall within a certain angular distance of the image.

(g) Facility for permitting the interpreter to assume a restful position with head and torso aligned instead of at 90° from each other, as at present. This should permit maximum circulation of blood through the interpreter's head and thereby permit him to maintain a high state of visual and mental acuity as previously discussed.

(h) Facility for permitting two or more interpreters to view the same stereoscopic model simultaneously, thereby enabling them (1) to perform an interpretation in different portions of the same stereo model simultaenously where time is of the essence and where, therefore, a pooling of effort is required, and (2) to use the so-called "conference" system of photo interpretation by means of which several interpreters can view a single stereoscopic image simultaneously and discuss its significance, thereby pooling their knowledge and presumably improving the accuracy of the interpretation.

(2) An Improved Type of Lens Stereoscope

Certain types of photo interpretation must be performed either in the field or under other adverse conditions which preclude the use of elaborate stereoscopic viewing equipment such as that just described. The lens stereoscope and opaque contact prints will no doubt continue to be the common tools used under such conditions. Recognizing this fact, photo interpreters recently have given much thought to the desirable attributes of a lens stereoscope. Most of these attributes which are relevant to the problem at hand can be grouped as follows:

(a) A good lens system. Two or three different magnifications are considered necessary and sufficient. These should include a 2 to 3 power magnification for hasty searching and interpretation of the over-all area covered in a stereo model; the lens system also should provide an 8 to 10 power magnification to permit enlargement of local detail to the maximum permitted by image sharpness on photography of good quality.

(b) Adequate illumination of the stereo image. Since natural, rather than artificial light usually is employed in lens stereoscopes, the obtaining of adequate illumination may become a problem at high magnifications in which the lens elements are quite close to the photos.

(c) Compactness. For field use there is much to be said in favor of a lens stereoscope that will fit in the interpreter's pocket when in the collapsed position.

(d) Stability. The high center of gravity resulting from a compound lens system tends to make the stereoscope top-heavy. Stability can of course be maintained by increasing the spread of the stereoscope's legs, but this feature may prevent adequate illumination of the prints and detract from the compactness of the instrument.

(e) Economy. In view of the extreme value of various types of photo interpretation data, it is perhaps false economy to equip photo interpreters with a $10 stereoscope if a $50 one, or even a $500 one, is decidedly superior. Even these larger sums represent but a fraction of the sum invested in photographic aircraft, cameras, films and processing equipment, all of which expenditures are to no avail unless the photo interpreter has adequate stereoscopic equipment for identifying images depicted on the resultant photography.

(3) A Photo Interpreter's Tally Register

This item of equipment is becoming of increasing importance with the increased use of aerial photos for inventory of fish, wildlife, trees, automobiles, personnel, etc. A suitable tally register should permit the photo interpreter to:

(a) Tally each individual image as he interprets it, thereby giving a cumulative total at any time without the interpreter's having to carry this total in his head.

(b) Permit the interpreter to place an identifying mark on each image as he tallies it, thereby removing the possibility for subsequent doubt as to which images have been tallied and which have not.

Certain tally registers which have recently been developed probably are adequate for use when interpreting photographic prints although some difficulty may be experienced in using these registers under the highest magnification of a lens stereoscope because of limited working space. To the speaker's knowledge no tally register is currently available which would satisfy requirement (b) above when interpreting transparencies projected onto a screen.

(4) Photo Inventory Templets

Recent photo interpretation experience in making inventories of trees, fish, waterfowl, and gregarious animals indicates the probable value of transparent templets which might be used as overlays to aerial photos when making such inventories. The following are examples of the possible uses for such templets.

(a) To delineate systematic search lanes on the photos in order to ensure that each area is thoroughly searched once and once only. An analysis of Fig. 17 might serve to indicate the appropriate width of each search lane.

(b) To indicate the location of mechanically-spaced or randomly-spaced sample plots on the photo. Such templets are useful when time limitations or economic considerations dictate the necessity for sampling an area rather than making a 100% tally.

(c) To provide density scale guides for use when the objects being inventoried are so clearly defined as to permit their density stratification.

(5) Photo Interpretation Keys

As most of us know, a photo interpretation key is reference material designed to facilitate rapid and accurate identification and determination of the significance of objects or conditions from the analysis of their photo images. Ideally, the key consists of two parts; (a) a collection of annotated or captioned stereograms and other photos which are illustrative of the objects or conditions to be identified and (b) a graphic or word description which sets forth in some systematic fashion the photo recognition features of those objects or conditions. Most of the current wave of enthusiasm for photo interpretation keys stems from the military requirement for training large numbers of photo interpreters in a short time to do some type of interpretation for which they have had little or no previous experience. While it has been amply demonstrated that properly-prepared photo interpretation keys are useful for meeting such emergencies, considerable criticism has been levelled at those who are inclined to oversell such keys.

Those interested in the present speaker's rather optimistic views on photo interpretation keys and in studying examples of such keys are referred to the June 1952 issue of

Photogrammetric Engineering. Particularly pertinent to our present discussion, however, are some of the words of caution that have been sounded relative to the use of such keys.

Whitmore (1953) states, "The idea of the photo interpretation key for the indoctrination of relatively untrained personnel is valid up to a point. It is based on the assumption that many classes of objects are readily identifiable and have the same significance wherever found. This is particularly true of works of man....... But there are other problems which cannot be solved (simply through use of a key) because of their complexity. The way to solve them is to develop more information concerning the area of interest, or to supply superior reasoning power to the evidence already available, or preferably both." Whitmore then gives examples of the effective use of such methods.

Frost (1953) points out that the user of a photo interpretation key "is limited by the background of the key maker as well as by his own background."

Finally, Colonel C. A. J. von Drabbe (1953), Chief of the Dutch Topographic Service, hops on and off the photo interpretation key bandwagon with the following amusing but well-taken comments.

"In order not to be misunderstood I wish to state that I realize the great value of photo interpretation keys. But from a scientifical point of view there is a great danger. Many people knowing almost nothing of photo interpretation will take a photograph, observe an object on it and identify it with page so and so of an interpretation key. This is an evil for we know too well how the aspect of any given object may change, depending on its natural circumstances......... If I must admit that I have studied and interpreted some 600,000 aerial photographs and that nowadays my knowledge of photo interpretation is still limited, then either you might consider me a person deprived of any intelligence or you might take photo interpretation to be an extremely difficult science. To make myself a compliment I believe the latter is true."

In concluding this section the speaker should like to agree with Colonel von Drabbe that photo interpretation is an extremely difficult science. The seeming requirement, particularly among the military, for a photo interpretation key, stems largely from the fact that frequently, during a training period of a few weeks, the photo interpretation student may be expected to learn to recognize virtually all natural and man-made features of the Earth's surface, and having recognized them to fit them into a pattern from which he can deduce the nature and significance of all activity in the area, past, present and future. It would be difficult to envisage a more comprehensive objective to be achieved in so short a training period. If this objective is to be realized, or even approximated, information given the student must be systematized and presented in as concise a manner as possible. When this has been done, a photo interpretation key has been prepared. Let us not create hostility toward the use of such an important document either by proclaiming it as the cure-all to every photo interpreter's problem, or by regarding it as an end in itself rather than as a means to an end.

(6) Other Items of Equipment

Among other items of P.I. equipment there are many so-called "scales" for use in determining or describing the size, shape, tone, texture, pattern, density, slope, height, etc. of various objects. Several of these are described and illustrated by the speaker in the June, 1952 issue of Photogrammetric Engineering so will not be discussed further here.

(C) TECHNIQUES EMPLOYED BY THE PHOTO INTERPRETER

In keeping with the subject matter thus far discussed in this paper, let us assume that photographs having suitable image characteristics have been made available to a photo interpreter having the proper physical and mental characteristics and that he also has been provided with adequate equipment for interpreting this photography. Now what techniques should he employ in interpreting this photography?

(1) General Techniques

There are certain methods or techniques, including the following, which are applicable to nearly all types of photo interpretation:

(a) Methods for oreienting a stereo model beneath the stereoscope.

The objective should be to accomplish this act quickly yet in such a way as to permit the most realistic 3-dimensional impression of the model, while avoiding unnecessary eyestrain for the interpreter (Ashenbrenner, 1952)

(b) Methods for systematically searching the area encompassed by a stereo model.

The possibility for delineating search lanes of a width commensurate with that of the human eye's field of view has already been discussed.

(c) Methods for avoiding duplication or omission in the interpretation of areas common to two or more models.

This is of such importance in the interpretation of end lap areas common to 3 successive photos in a flight line or sidelap areas common to 2 adjacent flight lines as to permit a reduction of from 30 to 50% in the photo area which otherwise would be interpreted.

(d) Methods for handling a large stack of photos in an orderly manner during the interpretation process.

The advantage of some system for the orderly progression of photos from one position to the next as a large stack of them is being interpreted can be very great. The advantage is apparent, however, only when contrasted with the haphazard crossings over and rotations of prints that usually ensue when an interpreter simply plops down a stack of photos and starts interpreting them.

The writer has expressed certain views relative to the above points in the chapter on photo interpretation in our Society's "Manual of Photogrammetry." Hence he will not elaborate further here. In connection with this discussion it is pertinent to note, however, that a well-qualified photo interpretation supervisor frequently judges an applicant's photo interpretation ability more by the way in which he handles photographs than by his statement of qualifications for the job.

(2) Specific Techniques

It certainly cannot be within the scope of this already very lengthy paper to catalogue or describe the specific photo interpretation techniques used by geologists, foresters, geographers, military photo interpreters and others. Even if we were to attempt to do so we would quickly run afoul of "trade secrets," and "security regulations" while at the same time delving into such details that any particular example would perhaps interest no more than 10% of our audience. It is far better that we merely refer those interested in some particular type of interpretation to the appropriate textbook, e.g., Eardley (1942); Smith (1943), Spurr (1948), etc., or to papers presented in past photo interpretation symposia and published in "Photogrammetric Engineering" or in the "International Archives of Photogrammetry."

The foregoing should not be interpreted as an attempt to minimize the importance of specific photo interpretation techniques. To the contrary, such techniques usually command the greatest emphasis and time when teaching a trainee to do a particular type of interpretation. Perhaps there is just one comment that is sufficiently applicable to most of these fields of interpretation to merit mention here:

When attempting to learn the techniques and methods for a particular type of interpretation the trainee should spend a great deal of time out in the field comparing that which he sees on the photos with the corresponding landscape as it lies before him. Only by so doing can he appreciate the significance of certain subtle photo image characteristics which he might otherwise overlook.

## SUMMARY

1. Photo interpretation is defined as the act of examining the photographic images of objects for the purpose of identifying the objects and deducing their significance.

2. Consistent with this definition, factors affecting photographic interpretation are discussed under two major headings: (a) factors governing the quality of photographic images, and (b) factors governing the perception and interpretation of photographic images.

3. The primary factors governing the quality of photographic images are: (a) tone and color characteristics, (b) image sharpness characteristics, and (c) stereoscopic parallax characteristics. Factors governing each of these characteristics are discussed.

4. The primary factors governing perception and interpretation of photographic images are: (a) visual and mental acuity of the photo interpreter, (b) characteristics of the photo interpreter's equipment, and (c) techniques employed by the photo interpreter. Each of these factors also is discussed.

## CONCLUSIONS

As indicated by the foregoing analysis, if reliable information is to be obtained by means of aerial photographic interpretation, a number of steps or processes must have preceded final derivation of the desired information. Specifically: (1) satisfactory photographic equipment must have been developed, including aircraft, cameras, mounts, films and filters; (2) adequately trained personnel must have operated this equipment in a satisfactory manner at the time of photography; (3) the resulting photography must have been properly processed in order to obtain satisfactory photo image characteristics of the objects to be interpreted; (4) suitable photo interpretation equipment must have been developed for use in viewing, measuring and interpreting the photo images; and (5) this equipment must have been correctly employed by a photo interpreter having the proper background of training and experience together with the necessary visual acuity.

These many steps which lead to the extraction of photo interpretation data have been likened to the links of a chain. From this analogy it has been incorrectly concluded that no strengthening of the photo interpretation chain can result except through a strengthening of its weakest link.

100 years ago in his famous "law of minimum" which he states as follows: "When a biological process is conditioned as to its rapidity by a number of factors, the rate of that process is limited by the pace of the slowest factor." Some 50 years later Mitscherlich made a revision in the law of minimum which photo interpreters could well emulate. Mitscherlich (1909) recognized, "When a biological process is conditioned as to its rapidity by a number of factors, the increase in rate produced by unit increment of <u>any</u> lacking factor is proportional to the decrement of that factor from the optimum." Let us suppose for example that the weakest link in the photo interpretation chain is the photo interpreter, himself. Some of our "Leibig-minded" photo interpreters have urged that in such a case we abandon all thought of improving any other link in the photo interpretation chain, such as image quality for example, until we have strengthened this weakest link. Here's hoping that it won't take the Mitscherlichs in our Society 50 years to convince the rest of us that improved photo image quality may benefit a poor interpreter as much as it may a good interpreter, and perhaps even more so. Viewing this matter more realistically, then, it would seem that we should strive, now, for improvements at <u>every</u> limiting link in the photo interpretation chain, with the hope that each improvement will increase the accuracy of the final information derived. At the same time, in allocating our overall research and development effort in the photo interpretation field we would do well to allocate our energies toward the improvement of any limiting factor in direct proportion to the decrement of that factor from the optimum.

We have seen from the various diagrams in this paper that we are now operating at the "toe" of the so-called threshold curve in each of several factors affecting photo interpretation. We also have seen, from the steepness of these curves, that much improvement in the dependent variable or ordinate may result from rather modest improvement in the independent variable or abscissa. Regardless of the absolute units in which these ordinates are expressed they can in most cases be translated to read "accuracy of photo interpretation." We therefore have reason to believe that the combined effects of these individual improvements all along the chain will produce a very appreciable cumulative improvement in the accuracy of our final photo interpretation data. For example, in the case of lens aberrations we are told that each improvement tends to be "proportional to its <u>square</u>, independent of the others." Some other improvements may be only additive insofar as their cumulative beneficial effects are concerned, and still others somewhat less than additive. But the essential point is that no possible means of improvement should be overlooked, at least at the initial analysis stage, as each may tend to improve to some extent the accuracy of our final photo interpretation result.

The foregoing analogy between photo interpretation as we find it today, and biology as it was known 50 or 100 years ago, sets the stage for the final point to be made in this paper. As the photo interpreter encounters new problems he should ask himself, "Is this a problem entirely peculiar to the field of photo interpretation or is it simply a new manifestation of a problem which has been previously dealt with in related sciences?" With surprising frequency he will find the latter to be the case and can profit accordingly. Thus by borrowing from the centuries-old experience of plant and animal taxonomists he may avoid many pitfalls in the construction of keys; by borrowing from the precise terminology of the mathematician or engineer, he may avoid the confusion which would result by introduction of his own jargon for describing shapes, patterns and other characteristics of photo images; by borrowing from the search techniques used by microscopists when they are studying slide specimens he may learn improved methods for the systematic search of a photograph; and by borrowing from the experience of oculists, doctors of medicine, and psychologists, he may gain for the first time an accurate insight into the physical and mental characteristics which are so critical in the making of a good photo interpreter. Such mass-borrowing of information is not a shameful practice, but an intelligent one. Furthermore, the photo interpreter can find consolation in the fact that for each bit of information he borrows, he offers repayment a hundredfold to those many fields which are finding photo interpretation to be the most reliable and economical source of much of the information which they so vitally need.

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Fig. 1 Spectral diagrams used in predicting or analyzing the tone characteristics of photographic images.

Fig. 2 Two aerial photographs of the same area obtained with panchromatic-minus blue and infrared-89A photography, respectively. Note that tone values are consistent in each case with those that might have been predicted by analysis of the curves in Fig. 1, i.e. All hardwoods appear light in tone and all conifers dark in tone on the infrared photo, but not on the panchromatic photo.

Fig. 3 Aerial oblique color photograph of portion of the city of Baltimore, Maryland, showing both the advantages and limitations of aerial color photography from the photo interpretation standpoint.

Fig. 4 Two prints made from the same negative, but on materials differing in their resolution characteristics. The material used in A had a maximum resolving power of 230 lines per millimeter, while that used in B had a maximum resolving power of only 130 lines per millimeter. Nevertheless B obviously produces a much sharper image than A because it provides higher acutance. (Photos are from article by Higgins and Jones, 1952.)

Fig. 5 Schematic diagram representing a knife-edge exposure and the microdensitometer trace, D, across the developed image. The straight line, E, between points A and B, and the hypothetical dotted curves, F and G, represent traces having the same average gradient as curve D. (After Higgins and Jones, 1952.) Significance of this curve in relation to resolution and acutance is explained in text.

Fig. 6 Two photographic reproductions of the same scene made at different focal settings. Fig. 4A was made at the focal setting giving maximum resolution; Fig. 4B at the focal setting giving maximum acutance. Image sharpness obviously is greater in B than in A, despite the higher resolution of the latter. (Photos are from Higgins and Jones, 1952.)

Fig. 7 Two photographs of the same resolution target printed on materials A & B having resolutions of 130 and 230 lines per millimeter, respectively taken at different focal settings of the camera. All other factors were the same in the two photos. The left photo gives better resolution for images of the size shown at top of the resolution target; conversely the right photo gives better image sharpness for bottom half of target. (Photos courtesy of Kodak Park Research Laboratories.)

Fig. 8 Diagram showing relation between image size and the focal setting required to give optimum image contrast. Note that there is no single "optimum focus." Compare with Fig. 7. (After Macdonald, 1952.)

Fig. 9 Curves showing two possible relationships between resolution and focal setting in an aerial camera lens system (assuming detail size constant). A lens system giving curve B probably would be preferable to one giving curve A since the latter would exhibit excessive loss of resolution when only slightly out of focus.

Fig. 10 Comparative magnitude of Motion Factors in 24-inch photography flown at 10,000 feet altitude, using Super-XX Emulsion, 1/150 second exposure and 200 miles per hour ground speed. (From Macdonald, 1952).

Fig. 11 Derivation of the parallax equation used in determining object heights from aerial photographs.

Fig. 12 Summary of problems relative to the obtaining of large scale stereoscopic photography from high altitudes. (After Aschenbrenner, 1950.)

Fig. 13 Photographs showing the appearance of a given area in four different seasonal states.

Fig. 14 Curve showing probability of detecting a small light-toned circular stimulus as a function of the contrast between that stimulus and the illuminated viewing screen upon which the stimulus is cast. Note that, within the threshold range, a 4-fold increase in relative contrast results in nearly a 10-fold increase in probability of detection. (After Blackwell, 1946.)

Fig. 15 Visual response, R, as a function of the degree of brightness, B. This curve emphasizes the difficulty of discerning objects in shaded areas since the eye is less sensitive to tone changes at such low brightness values. (Note: This curve is merely a hasty freehand sketch based upon unpublished data of Higgins and Jones.)

Fig. 16 Curve showing light sensitivity of the human eye in relation to wave length of light. (From PIC Training Manual No. 1; ordinate units unspecified.)

Fig. 17 Relation between visual acuity and angular or linear separation of the retinal image from the exact center of the fovea. (After Higgins and Jones, 1947.)

Fig. 18 Schematic diagram showing the way in which a visual field is scanned in making an analysis of photographic edge gradients. (From Jones and Higgins, 1947.)

Fig. 19 Effect of diameter of pupil of the eye on visual acuity. (Based on unpublished data of Higgins and Jones.)

Fig. 20 The contrast threshold curve (from Macdonald, 1951). For explanation of its significance to the interpretation of photographic images, see text.

*See pages 33 and 34 for captions to all figures.*

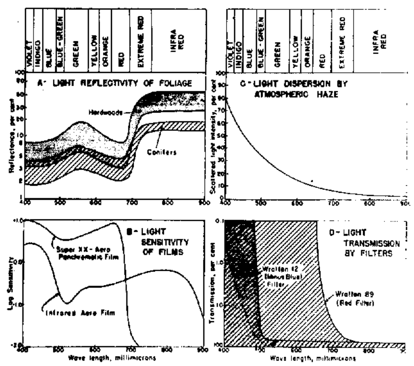



Figure 1.

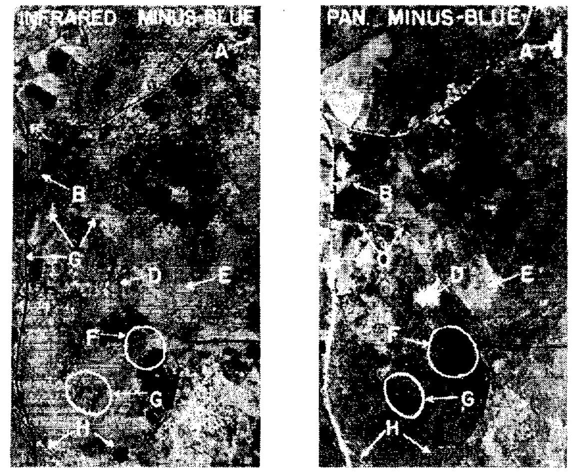



Figure 2.

*[Fig. 3, a color photo, is missing.]*

A Figure 4. B

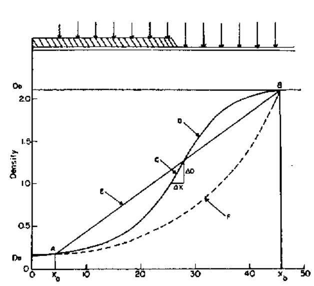
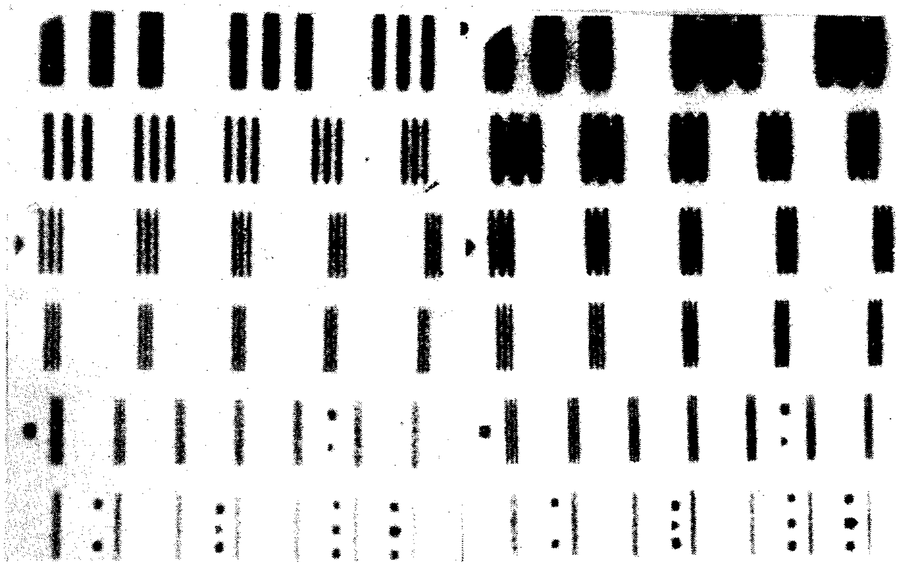



Figure 5.

A Figure 6. B



A Figure 7. B

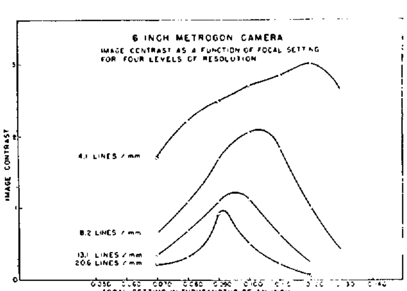



Figure 8.

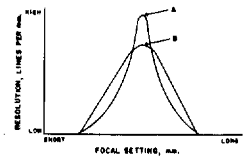



Figure 9.

| TYPE OF MOTION | MEDIAN IMAGE BLUR | |
|---|---|---|
| | IN FLIGHT LINE | ACROSS FLIGHT LINE |
| 1. Translational Motion of Aircraft | 0.119 mm.$^{-1}$ | 0.000 mm.$^{-1}$ |
| 2. a) Aircraft Pitch | 0.008 mm.$^{-1}$ | ——— |
| b) Aircraft Roll | ——— | 0.015 mm.$^{-1}$ |
| c) Camera Mount Pitch | 0.011 mm.$^{-1}$ | ——— |
| d) Camera Mount Roll | ——— | 0.016 mm.$^{-1}$ |
| e) Aircraft and Camera Yaw | 0.001 mm.$^{-1}$ | 0.001 mm.$^{-1}$ |
| 3. Lens and Film (Vibrational) Motion | 0.040 mm.$^{-1}$ | 0.040 mm.$^{-1}$ |

Figure 10.

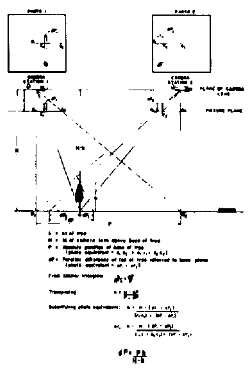


Figure 11.

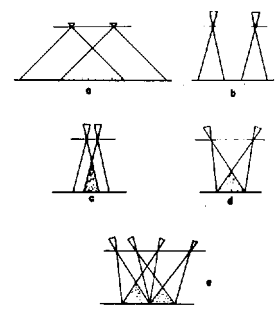
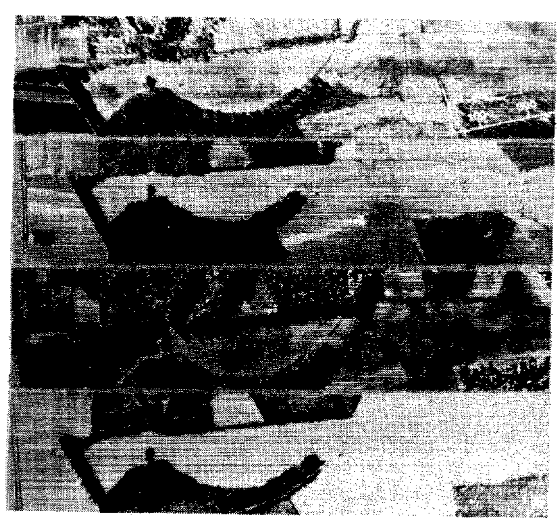



Figure 12.



*Spring*

*Summer*

*Fall*

*Winter*

Figure 13.

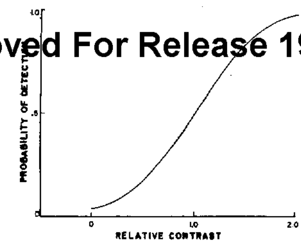



Figure 14.

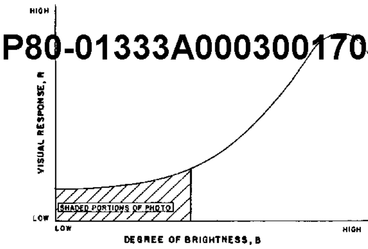



Figure 15.

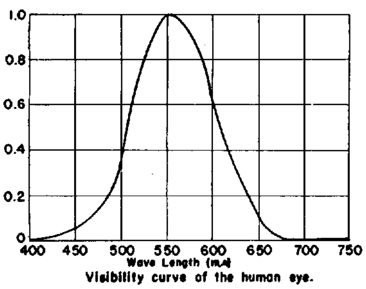



Figure 16.

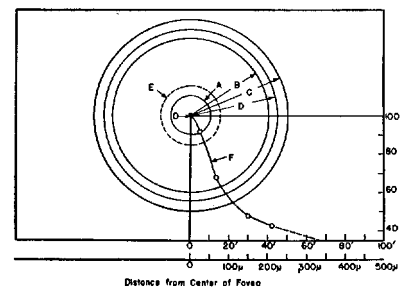



Figure 17.

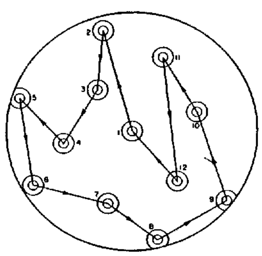



Figure 18.

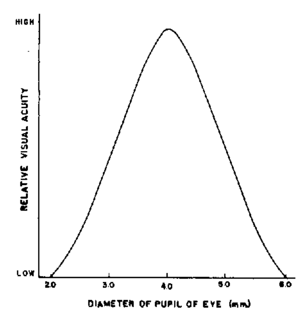



Figure 19.

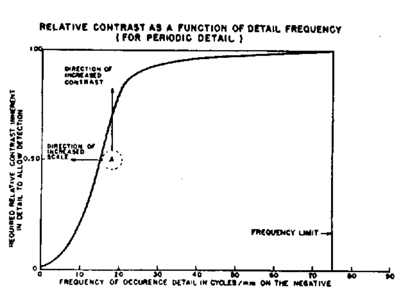



Figure 20.