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Variable Flight Parameters for SLAR

The thematic line maps needed for an integrated evaluation of the natural resources and planning of future development of a nation can be derived from side-looking radar imagery at a scale useful for reconnaissance and exploration.

Abstract: *Some variable flight-parameters for a SLAR survey such as flight altitude, scan direction, sidelap for monoscopic or stereoscopic viewing and complementary aerial photography are treated with respect to the terrain type to be surveyed. The need in developing countries for fast information over extensive areas is met by the SLAR imaging system by providing small-scale images with clear relief expression on a 24-hour-per-day basis.*

Introduction

Side-looking radar projects covering large areas in the humid tropics have prompted the author to consider the use of radar imagery for thematic mapping. Adverse weather conditions and remoteness of the areas are often an important delaying factor in the acquisition of aerial photographs. The atmospheric penetration capability of radar makes SLAR a fast-working survey system. Three commercial systems are at present operating independent of military and research equipment: Goodyear, Motorola and Westinghouse.

The Goodyear system is the APQ 102, using *x*-band (3.1-cm wavelength) and a synthetic aperture antenna. The acquisition scale of the images is 1:400,000. The maximum swath width is 37 km. Flying height is variable between 6,000 and 12,500 meters with variable depression angles. Resolution is 16 meters in range direction and 16 meters in azimuth direction.

The Motorola system is the APS 94 (D), using *x*-band (2.5 cm), real aperture antenna. The acquisition scale is 1:500,000. The maximum swath width is 100 km. Flying height is normally 3,500 meters. Resolution in range direction is 30 meters and in azimuth 48 meters for near range and 116 meters for far range.

The Westinghouse system is the APQ 97, using the *Ka* band (8.6-mm wavelength) with real aperture antenna. The acquisition scale is 1:250,000. The maximum swath width is 21 km. The flying height depends on aircraft capability and depression angle can be varied. Resolution for 6,000-meters altitude is 11 meters in range and 10 meters in azimuth direction for near range and 22 meters azimuth for far range. Resolution deteriorates with increased flying height.

Variables in Flight Planning

For a flight plan of a side-looking radar survey, some system parameters may be selected with respect to terrain type and objectives of the survey, namely:

- Flight altitude related to depression angle
- Scan direction
- Sidelap of strips
- Additional photography.

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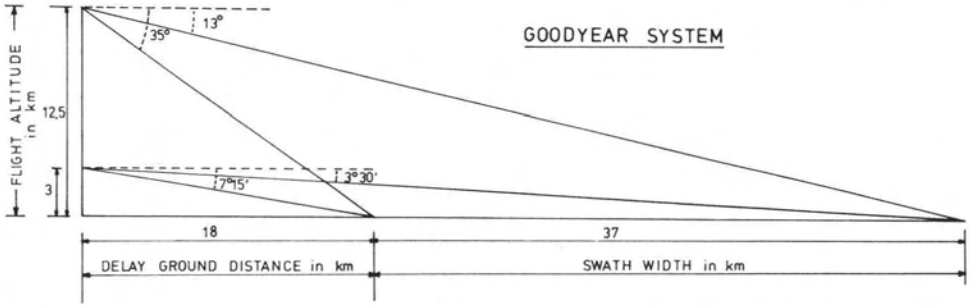

FIG. 1. Relation between flight elevation and depression angle for the Goodyear SLAR system.

FLIGHT ALTITUDE

The delay ground-distance and the ground swath for the Goodyear system are programmed as constant with varying flight heights being 18 and 37 km (Figure 1), respectively. Depression angles vary between 13° and 35° for, far range and near range, respectively, at a flight altitude above terrain of 12. 5 km, and 3°30′ and 7°15′ at a flight altitude of 3 km.

The Westinghouse system varies delay ground-distance and swath width with varying flight heights. For 6.1 km flight altitude the swath width is 18.8 km and the depression angles 16° and 70° for far range and near range, respectively. For a flight altitude of 11 km these angles will be 21° and 59°, respectively, with a maximum swath width of 21 km (Figure 2).

To select the appropriate flying height and depression angle for the survey the following points should be taken into consideration:

- ★ Relief. (a) In mountainous areas, radar shadow will obscure large areas and relief displacement will be present. (b) In flat areas exaggeration of relief can be created by increased radar shadows.
- ★ Atmospheric interference, flight stability.
- ★ Spatial resolution.
- ★ Simultaneous aerial photograph coverage.

In low-relief areas the expression of small elevation differences is desirable. For example, drainage channels in tropical forest areas are hardly visible with high depression angles. Low depression angles are favorable to exaggerate the relief impression, whence flying heights should be reduced.

In mountainous zones, where relief differences are considerable, radar shadows will be excessive with low depression angles. Radar shadow areas are entirely black and lack any information. From this point of view a greater flying height with larger depression angles will result in smaller shadow zones and relatively more information. On the other hand, relief displacement will increase with higher depression angles. The slopes dipping towards the flight line will appear steeper at high depression angles than at low depression angles. In strong relief areas and with high depression angles this often results in *lay over* (the appearance of overhanging slopes in the image). To eliminate the lack of information from radar shadows, high-relief

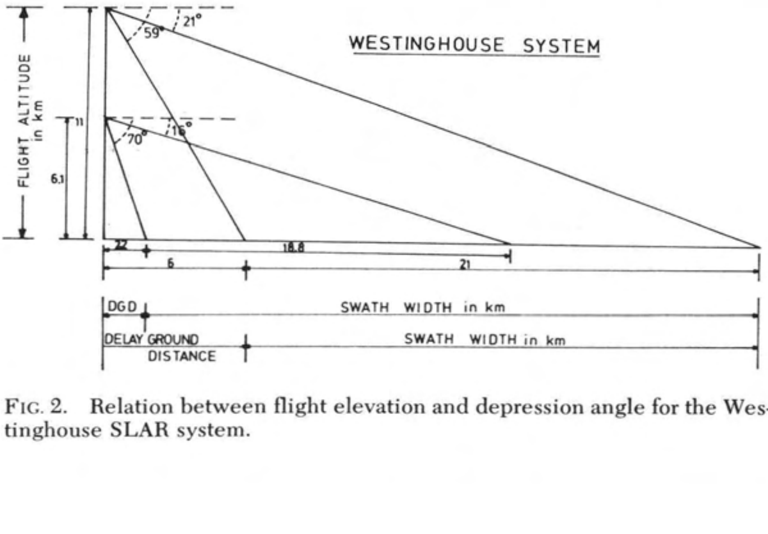

FIG. 2. Relation between flight elevation and depression angle for the Westinghouse SLAR system.

zones might be flown, for example, twice with opposite scan directions.

Atmospheric interference is mainly related to flight instability. The attenuation might slightly increase due to the greater thickness of the atmosphere to be penetrated with greater flying heights; this, however, is small compared to the attenuation occurring at lower levels where scattering by cloud and dust (Mie scattering) is manifold. More important is the flight stability. The antennas are normally stabilized, but with heavy turbulence the stabilization might not be sufficient and movement of the antenna will degrade the image. In general it can be stated that at higher elevations less turbulence will occur.

The spatial resolution in azimuth will not change with varying flying heights for a synthetic aperture radar. For real aperture radar this is however the case. (Figure 3). The resolution in azimuth will deteriorate with increased flying height and ground range.

The selection of flying height in relation to simultaneous aerial photograph coverage is treated later.

SCAN DIRECTION

Scan direction has to be chosen in relation to the main trend of the morphological framework of the area (Eppes, 1971; MacDonald, et al., 1969). Features running parallel with the scan direction are in general not expressed strongly in the image and might be easily overlooked during interpretation. For geological purposes the scan direction should be roughly perpendicular to the major structural and topographic trends. The fine drainage network of trellis type in flat terrain might make a particular flight direction (scan direction) advisable. To make a comparison with ERTS imagery (Earth Resources Technology Satellite) easier, flight direction for SLAR has been occasionally selected parallel to the satellite path with the look direction towards the west to create a shadow orientation similar to that for early morning ERTS imagery. For high-relief areas multiple scan directions might be advisable for obtaining information also of the extensive shadow areas.

SIDELAP FOR RADAR STRIPS

For low-relief areas a 10-20 percent sidelap may be sufficient; for high-relief areas this should be increased to 30 percent for monoscopic viewing. More important is, however, the choice between a monoscopic or stereoscopic studying of radar imagery. Koopmans (1973) came to the conclusion that to obtain drainage information to be used for base-map construction of low-relief areas, stereo radar interpretation was of far greater accuracy, qualitatively as well as quantitatively, than monoscopic radar interpretation. The same is true for thematic interpretation of radar imagery.

A three-dimensional image obtained by stereoscopic viewing of subsequent radar strips (with look direction in the same way) will give the professional interpreter far more, and more accurate, information than monoscopic visual interpretation. For stereo viewing, a 60 percent sidelap is necessary. Parallel flight lines and a good spatial fidelity are required for obtaining a stereo image.

A stereo image will also allow one to make

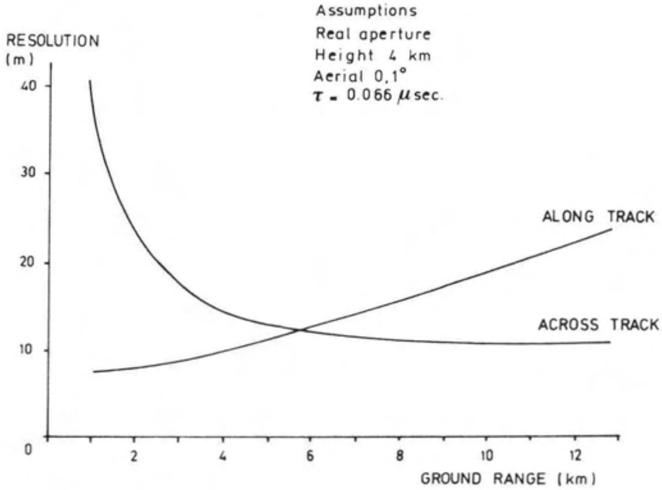

FIG. 3. Variation of ground resolution (after Grant).

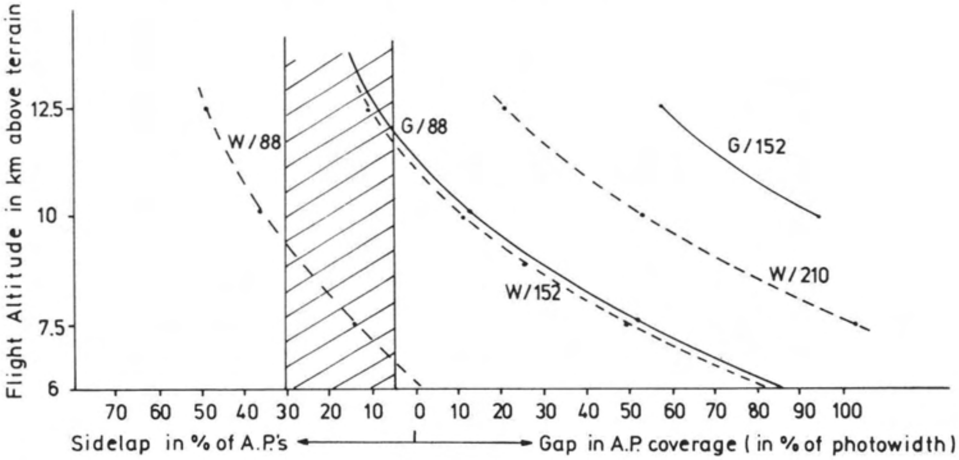

FIG. 4. Sidelap or side gap of consecutive strips of aerial photographs related to flight elevation above terrain. The flight-line spacing is considered to be the same as SLAR system used: *G*, Goodyear; *W*, Westinghouse.

measurements for height and slope angle of the images (Leberl 1973).

The cost will increase as flight line spacing becomes smaller. The number of flight kilometers to be flown will approximately double.

ADDITIONAL DATA FROM AERIAL PHOTOGRAPHS

Aerial photographs may be obtained by making use of additional remote sensing capabilities during the radar flight. These aerial photographs can be of great help for control of radar imagery and cartographic mapping if they are not restricted to single exposures. Moreover, they can be used in later phases of the survey for semi-detailed, or detailed, thematic mapping. In the RADAM project of BRAZIL large areas were covered with aerial photographs in addition to the SLAR images during the radar flights.

The relations between radar sidelap and aerial photograph sidelap for different lens systems and flight elevations have to be considered. As seen before, the companies fly with varying ground swath widths: Motorola 100 km, Goodyear 37 km, and Westinghouse 21 km swath width. For the Motorola system the swath width is too great to allow aerial photograph sidelap. Taking a radar sidelap of 20 percent the flight lines for the Goodyear system will be 29.6 km apart, and for the Westinghouse system 16.8 km. For a 60 percent sidelap in the radar images, to make stereo viewing possible, these amounts of interspace between flight lines will be respectively 14.8 km and 8.4 km.

Let us consider first those radar images flown with 20 percent sidelap of the strips, which means a fixed flight-line spacing but varying flying heights. The sidelap of the aerial photograph runs taken during the same flight, with a normal aerial camera (e.g., a Wild RC8, aerial photo size 23 by 23 cm) will vary with lens system (normal, wide-angle, super-wide-angle) and with flying height. In Figure 4 the varying heights are plotted against sidelap of aerial photographs for systems flying 20 percent radar sidelap. The curves are plotted for the Westinghouse system with normal swath width and aerial camera with focal lengths of 88 mm, 152 mm and 210 mm, or super-wide-angle, wide-angle and normal-angle, respectively. For the Goodyear system with different flight spacings, similar curves are plotted for the same three possibilities of camera lens-systems.

For the normal-angle lenses we can see that no sidelap is obtained in the subsequent aerial photograph strips. The Goodyear system using an 88-mm aerial camera and flying height above 12 km will supply aerial photographs with a small sidelap. The Westinghouse system provides a good sidelap for the aerial photos if flying above 6 km with a super-wide-angle lens, or above 12 km with a wide-angle lens system. In the graph the crosshatched zone indicates the optimal area for sidelap of aerial photograph strips of 5 to 30 percent. For higher relief areas, a 5 percent sidelap might not be sufficient.

Figure 5 shows the same for SLAR systems flying 60 percent radar sidelap, which means that the flight-line spacing will be much smaller. Consequently the sidelap in aerial photograph strips will be larger. For the Goodyear system the use of a wide-angle

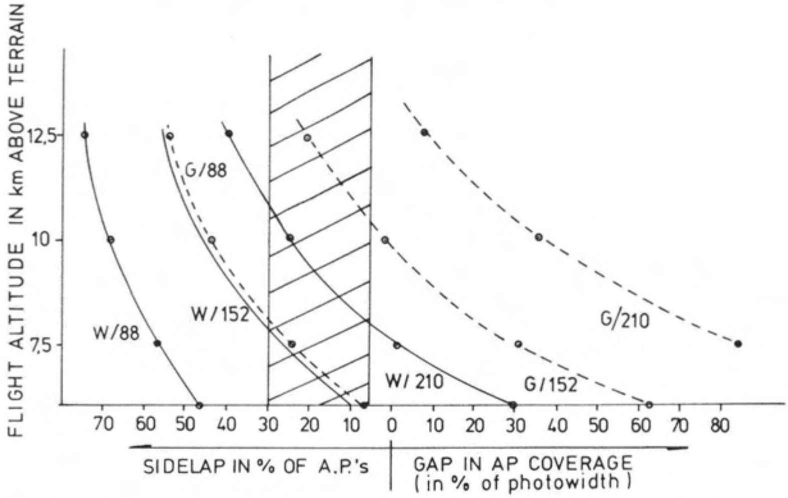

FIG. 5. Similar to Figure 4 but where the required sidelap for the radar strips is 60 percent.

camera system at a flying height of 10,500 meters and higher will be optimal.

For a lower flying height a super wide-angle lens should be used. For the Westinghouse system a 210-mm focal distance should be used for flight elevations between 8,000 and 11,000 meters. For lower flying heights a better sidelap is obtained with a camera with focal distance of 152 mm.

It is interesting to see the consequence of the varying flying heights and focal distances for the variation of the scale of the aerial photographs obtained. Figure 6 shows us the scale against flying height for cameras with 88, 152, and 210-mm focal length. The cross-hatched zones indicate the optimal zones to obtain sufficient sidelap on the aerial photo strips (5-30 percent) for the Goodyear system (*G*) and Westinghouse system (*W*) flying respectively, with flight-line interspacing of 29.6 and 16.8 km (20 percent radar sidelap).

Figure 7 shows a similar relationship for flight-line spacing based on 60 percent radar sidelap for stereoviewing (Goodyear, 14.8 km, Westinghouse, 8.4 km). The optimal zones for aerial photograph sidelap are again indicated for 5-30 percent aerial photograph sidelap. These graphs do teach us that for

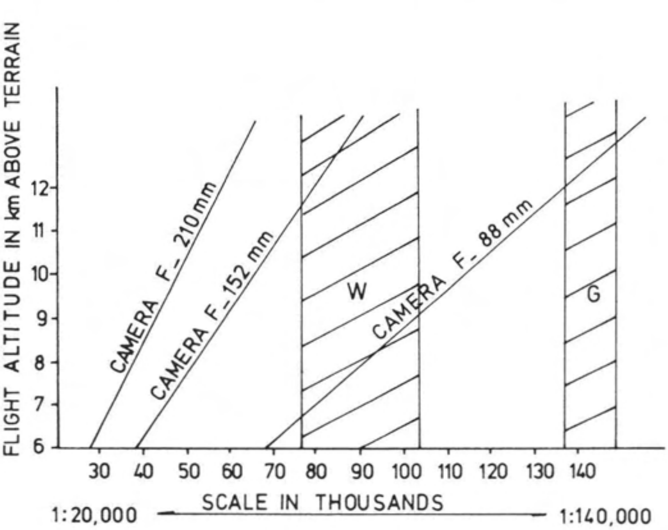

FIG. 6. Scale of aerial photographs relative to flight elevation for normal-angle, wide-angle and superwide-angle lenses.

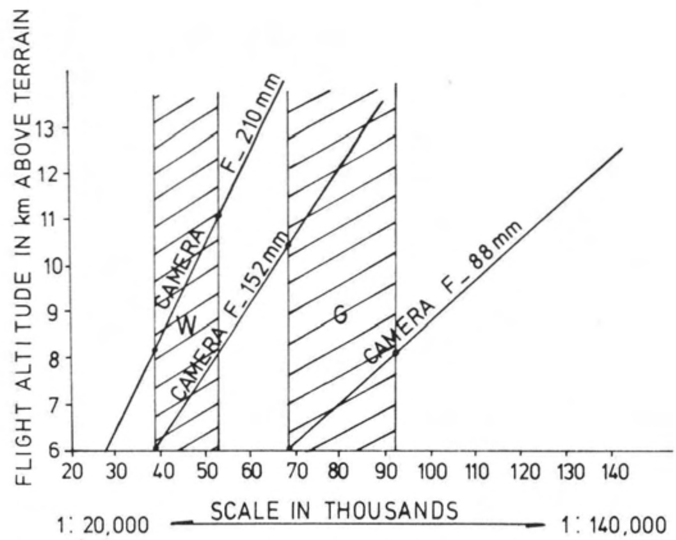

FIG. 7. Similar to Figure 6 but where the radar sidelap is 60 percent.

Westinghouse we should use for a scale 1:40,000 to 1:50,000, a 210-mm focal distance and with flight elevations of 8,000 to 11,000 meters. If preferring lower flying heights we should use the 152-mm focal distance obtaining similar sidelap and similar scale.

Goodyear will give optimal sidelap only in the 1:70,000 to 1:90,000 scales. Larger-scale aerial photography can be obtained but the aerial coverage will show gaps. A full coverage can only be acquired by using a super wide-angle lens (88 mm focal distance) at flying heights above 12,000 meters over the terrain if flying 20 percent radar sidelap for Goodyear.

Another aspect one must consider is the relationship between the number of aerial photographs necessary per 1000 square kilometers and the scale of the aerial photographs. A larger number of aerial photographs will influence, first of all, the cost of materials, printing costs, etc. and, secondly,

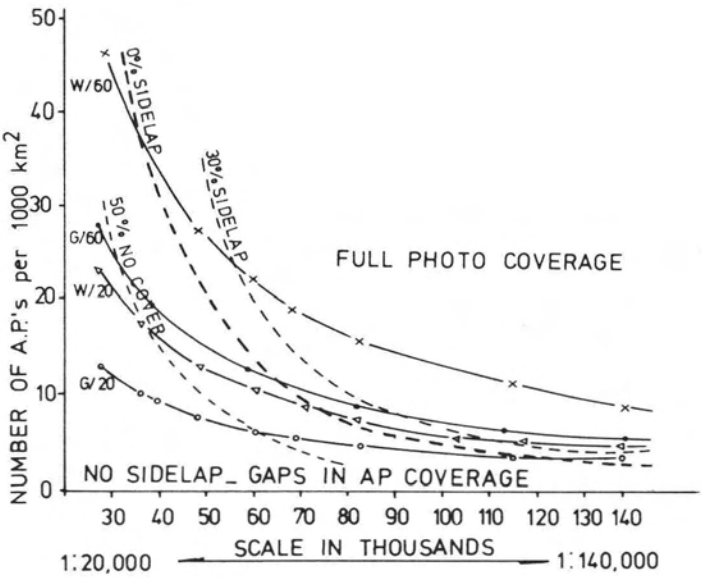

FIG. 8. Number of aerial photographs per 1000 km² for coverage at different scales.

the higher cost for interpretation time. Figure 8 shows us the relationship for normal size aerial photographs of 23 by 23 cm with 60 percent overlap. The flight line interspacing depends on the swath width of the radar system to be used and the recommended sidelap of the radar images of 20 percent for monoscopic viewing, or 60 percent for stereoscopic viewing of the radar. The heavy dashed line separates the zone where full aerial photo coverage is obtained from the zone where gaps in the aerial photograph coverage will occur. The light dashed lines are for a sidelap of 30 percent for aerial photographs (upper line) and for a 50 percent of area lacking in aerial photograph coverage (lower line).

In the range 1:70,000 to 1:80,000, Goodyear with a 60 percent sidelap for radar images, and Westinghouse with a 20 sidelap for radar images will need about 10 aerial photographs per 1,000 square kilometers (forward overlap of 60 percent for aerial photos); for Westinghouse with 60 percent sidelap for radar images and full aerial photograph coverage about 25 to 30 prints will be required per 1000 square kilometers for scales 1:45,000 to 1:55,000 (60 percent forward overlap for aerial photographs).

The cost increase for this additional aerial photograph coverage flown at the same time as the radar survey is relatively low. It is advisable to attempt to obtain a part from the SLAR images, as much aerial photographic coverage as possible at a scale which should be chosen relative to the type of survey to be made.

Radar Surveys for Developing Countries

In many developing nations where large parts of the country are not yet mapped or even photographed, pressure is rapidly building up to develop such areas for natural resources exploration, land development schemes, settlement, etc. By that time it is too late to start a normal or, even, crash mapping program. To channel development in an early stage the government planning agency should have some type of topographic base map and a rough insight into the potentials of the natural resources of the area. There is no need for great perfection or detail for this first type of exploratory surveys.

The atmospheric penetration capability of radar makes this surveying system optimal for the areas of the equatorial belt with humid tropical climates and adverse weather conditions.

The thematic line maps necessary for an integrated evaluation of the natural resources and planning of the future development can be derived from side-looking radar images at a reconnaissance-to-exploratory scale. Aerial photos obtained during the same radar flight (if weather permits) or flown over selected areas at a later stage will allow further semi-detailed or detailed surveys at a higher cartographic precision.

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Acknowledgment

Although the change in corporate name of Hobrough Limited to Gestalt International Limited was correctly reported in the August 1974 *Newsletter*, it was not changed in the listing of Sustaining Member companies. This correction has now been made.