Strike Reconnaissance," *WADD Technical Report 60-521.* August 1960.
201. Winterberg, R. P. and Wulfeck, J. W. "Investigation of Additive Color Photography and Projection for Military Photo-Interpretation. III. Comparison of Additive Color and Panchromatic Aerial Photography," Contract Nonr 3137(00), Dunlap and Associates, Inc., Santa Monica, California. February 1962.
202. Winterberg, R. P. and Wulfeck, J. W. "Investigation of Additive Color Photography and Projection for Military Photo-Interpretation. IV. Review of Program and Comparison of Additive Color with Typical Panchromatic Photography. Contract Nonr 3137(00), Dunlap and Associates, Inc., Santa Monica, California. March 1962.
203. Wolfe, R. N. "Width of the Human Visual Spread Function as Determined Psychometrically," *J. Opt. Soc. Am.*, 52: 460–469. 1952.
204. Wulfeck, J. W. and Taylor, J. H. (editors). "Form Discrimination as Related to Military Problems," *Publication 561*, National Academy of Sciences—National Research Council, Washington, D. C.
205. Wulfeck, J. W., Weisz, A., and Raben, M. W. "Vision in Military Aviation," *WADC Technical Report 58-399.* November 1958.
206. Yeslin, A. R. and Kraft, C. L. "Dynamic Airborne Reconnaissance Display Effectiveness as a Function of Display Scale: Identification as a Function of Image Size and Display Time as Imposed by Low-Altitude, High-Speed Flight and Side-Looking Sensors," The Boeing Company, Document D2-10212. 1960.
207. Zeidner, J., Sadacca, R., and Schwartz, A. I. "The Value of Stereoscopic Viewing," *HFRB Technical Research Note No. 114.* June 1961.
208. Zeidner, J. "Some Human Factors Studies in the Army's Command Control Information Systems 1970," paper presented at the 10th Military Operations Research Symposium, Santa Monica, California, U. S. Army Personnel Research Office publication. 16 October 1962.
209. Zeidner, J. and Birnbaum, A. H. "Survey of Psychological Studies in Image Interpretation, U. S. Army Personnel Research Office publication, *Research Study 59-1.* February 1959.
210. Zwieg, H. J., Higgins, G. C., and MacAdam, D. L. "On the Information-Detection Capacity of Photographic Emulsions," *J.O.S.A.*, vol. 48, p. 926. 1958.

*Technical Aspects of Air Photo Interpretation in the Soviet Union**

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ABSTRACT: *The present article reviews some technical aspects of air photography and air photo interpretation in the Soviet Union, taken from the Russian literature concerned with the subject and published after World War II. The most important technical means involved in the whole process of air photo interpretation are briefly outlined in the introductory section. In the two following sections the properties of the equipment used in air photography, such as cameras, lenses, films, and filters and their suitability for different surveying and interpretation purposes are dealt with in detail. The information presented in this paper may afford a contribution to a better knowledge of Soviet photo interpretation and to a basis for comparing its status with the one in western countries.*

SINCE the article by Troll "Fortschritte der wissenschaftlichen Luftbildforschung," which appeared in 1943 and contained a section on photo interpretation in the USSR, very little has become known about the further development of Russian air photography and interpretation methods and techniques. For example, in PHOTOGRAMMETRIC

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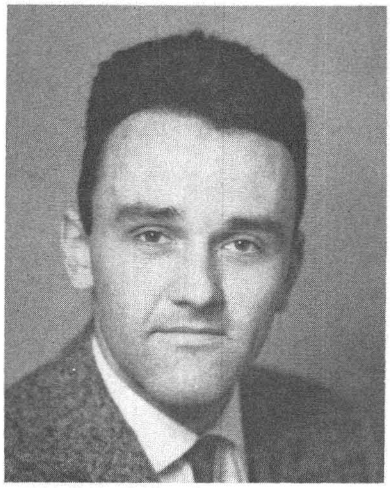
ENGINEERING the paper by Pestrecov on Russian optics in 1954 has been the only article dealing with this subject. This situation has been attributed to the lack of knowledge of the Russian language in western countries; to the scantiness of Russian publications translated into one of the western languages; and to the absence of the relevant literature in many of our libraries. In the present paper, therefore, the author tries to review some technical aspects of air photography and air photo interpretation in the Soviet Union, observed from the Russian literature dealing with the subject and published after World War II. It is not the main goal of this paper to compare American and Russian photo interpretation procedures but instead to convey some of the basic information indispensable for such a comparison.



DIETER STEINER

GENERAL OUTLINE OF THE TECHNICAL MEANS INVOLVED IN SOVIET AIR PHOTO INTERPRETATION[1]

The leading Soviet institutions in the fields of air photography and air photo interpretation are the Central Scientific Research Institute for Geodesy, Air Photography, and Cartography ("Tsentral'nyĭ Nauchno-Issledovatel'skiĭ Institut Geodezii, Aeros"emki i Kartografii"[2] = TsNIIGAiK), the Moscow Institute for Engineers of Geodesy, Air Photography, and Cartography ("Moskovskiĭ Institut Inzhenerov Geodezii, Aerofotos"emki i Kartografii" = MIIGAiK), and the Laboratory for Aeromethods in the Academy of Sciences ("Laboratoriia" Aerometodov Akademii Nauk" = LAER AN). From the publications by these institutes we have gained the largest part of the information presented in this paper.

Very much work has been carried out on measurements of spectral reflectance. As is known such investigations serve the purpose of providing specifications with regard to the selection of the technical means to be applied for particular problems in surveying from the air. The comprehensive work of Krinov (1947) is well known, because it has been translated into English. However, since then the findings of a large amount of investigations undertaken with improved equipment have been published with the result that Krinov's book has become obsolete. Reflection measurements are taken not only on the ground but very often from the plane as well. In both cases a variety of special instruments have been constructed. The objects measured are on the one hand vegetation complexes, single plant species (crowns of trees or shrubs), or parts of them such as branches, leaves, needles; and on the other hand the objects measured are different types of soils, surface materials, and bedrock. The results obtained so far show that the reflectance is dependant on the season, the geographical location, the direction of observation, and various other factors.

The selection of the kind of photographic equipment appropriate to different interpretation purposes, which relies partly on the results of the above mentioned reflection measurements, and partly on direct comparative experimental air photography, is the subject of many Russian articles. Problems of film-filter combinations in the first place have been discussed a great deal. All the technical means used in Russian air photography such as cameras, lenses, and light-sensitive materials will be reviewed in detail in the two main chapters of this paper.

On the side of the evaluating and interpreting aerial photographs there is an increasing trend towards more objective methods. This involves the utilization of instrumental means instead of the mere visual investigation and the approach towards a more systematic classification of interpretation criteria such as tone, texture, stereoscopic appearance, etc.

[1] This outline is based on general textbooks on air photo interpretation such as the one by Gospodinov (1961) but also on a variety of special papers which cannot be cited here.

[2] The system of transliteration applied here is the one used by the Library of Congress.

Most of the methods suggested and discussed are, however, still in the experimental stage. One of them is the microphotographic analysis that is conducted with considerably enlarged sections cut out from air photographs and applied in the first place to the interpretation of the plant cover. Another method is the photometrical method which consists in the measurement of optical densities on the negative. It may be applied to the determination of mean densities or for the microdensitometric scanning along profiles running over the bare soil or vegetation complexes. The curves thus obtained can be evaluated statistically in that one compiles a distribution curve for the location of the maximum and minimum values on the density scale. A similar method can also be used for the evaluating transparent color photographs: the densities of the single layers are measured monochromatically through appropriate interference filters step-by-step. An interesting method is the statistical treatment of plant dispersion, this may be of importance in dry regions with a sparse vegetation cover.

Many of the Soviet stereoscopes are designed for the simultaneous observation of photographs of different scales and are used for transferring details from single photographs to photoplans. It may come as a surprise that hardly any simple mapping instruments such as the Sketchmaster, the Radial Line Plotter, etc. are in use. This, at least, is the picture conveyed by the literature checked.

CAMERAS AND LENSES[3]

The camera used most frequently in all civil organizations is the fully automatic AFA-TE (Abbreviation for "Aerofotoapparat topograficheskiĭ-elektricheskiĭ"),[4] which has been designed and developed at the T͡sNIIGAiK. It supersedes the formerly popular Zeiss-RMK and the American K-17 since 1955 when its commercial production was started. The photo size is 18×18 cm. (7.1×7.1″). The camera is useful for mapping in most scales since it can be combined with a large variety of lenses, the focal-length of which ranges between 36 and 500 mm. (1.4 and 19.7″). Most of these lenses have been designed by the well-known engineer Rusinov at the Leningrad Institute for Precise Mechanics and Optics ("Leningradskiĭ Institut Tochnoĭ Mekhaniki i Optiki"). Special mention should be made of the lens with the shortest focal-length used so far, the Russar-38, which has an angular field of 148°.

When observing the data for the maximum shutter speed as reported in Table 1 the surprising fact is that the values are quite low and do not reach more than 1/300 or 1/400 sec. According to Veselovskiĭ (1958), however, newer improved models permit exposure times as low as 1/1000 sec.

The camera of the type AFA-33 with a photo size of 30×30 cm. (11.8×11.8″) was constructed during World War II and has become obsolete; but the camera is still in use for large-scale photography, e.g., for the survey of urban areas and for engineering purposes. The main drawback of this camera is the insufficient flattening of the film at the time of exposure.

The AFA-33-M is a modernized version of the AFA-33 for which a set of four lenses with focal-lengths of 200 mm. (7.9″), 500 mm. (19.7″), 750 mm. (29.5″), and 1,000 mm. (39.4″) is provided. It is convenient for performing various kinds of photography.

The AFA-37 with the Russar-29 lens and a photo-size of 18×18 cm. (7.1×7.1″) is useful for cartographic purposes and reconnaissance surveys. The first version, however, was not quite satisfactory; an improved one can be expected soon.

It is a general rule that lenses with a focal-length of 200 mm. (7.9″) and less are equipped with a between-the-lens shutter; those with a focal-length exceeding 200 mm. with a focal-plane or a Louvre shutter.

The shutterless AShChAFA camera obviously corresponds to the American Continuous Strip camera. According to Gordeev (in Belov 1959) it has been successfully used for photographing and identifying tree species in winter time at a scale of 1:500. The costs for such a type of photography are, however,

[3] This and the following section on films and filters are, except for some minor changes, a translation of the first part of chapter 4 of the author's article in German "Luftaufnahme und Luftbildinterpretation in der Sowjetunion" to be published in "Erkunde" no. 1, 1963. The information given in both sections has, if not otherwise stated, been gained mainly from the publications of Belov (1959), Belov and Berezin (1958), Gerasimova (1961), Mikhailov (1961), Shershen (1958), Smirnov (1960), T͡syganov (1960), and Veselovskiĭ (1958).

[4] For this and all other cameras mentioned see the detailed technical data in Table 1.

TABLE 1

TECHNICAL DATA OF SOVIET AIR PHOTO CAMERAS AND LENSES

Compiled from information given in the publication of Belov (1959), Gerasimova (1961), Il'in und Dervis (1962), Rusinov (1959), Shershen (1958), T͡syganov (1960), Veselovskiĭ (1958), and Zaitov and T͡suprun (1962)

Camera	Lens	Photo size [cm]	Focal length [mm.]	Angular field [o]	Relat. Aperture	Shutter	Shutter speeds [sec.]	Filter	Resolving power [1/mm.]						Relative illuminance at edge [%]
									Visual		Photographic				
											In laboratory		On airphoto		
									Centre	Edge	Centre	Edge	Centre	Edge	
AFA-TE	Ortoniar-13	18×18	500	29	1:7	L	1/100–1/300		240		30–40	18–25			
ibid.	Tafar-3	*ibid.*	350	40	1:6	L	1/100–1/300	i'ch.	285		35–40	25–30			82
ibid.	Russar-Plasmat	*ibid.*	200	65	1:6.3	B-t-l	1/40–1/120	i'ch.	165–190	41–83	25–45	15–24			58
ibid.	Russar-35	*ibid.*	200	65	1:9						35–53	32	23	18	
ibid.	Russar-43	*ibid.*	140	85	1:6.8						36	18–20			
ibid.	Russar-33	*ibid.*	100	104	1:6.3	B-t-l	1/90–1/225	ZhS-18	165–190	41–83	25–36	12–19			26
ibid.	Russar-29	*ibid.*	70	122	1:6.3	B-t-l	1/100–1/350	ZhS-18	225–250	55–112	25–36	10–15			10
ibid.	Russar-25	*ibid.*	70	122	1:6.8				150						10
ibid.	Rodina-2B	*ibid.*	55	133	1:8.2	B-t-l	1/100–1/350	ZhS-18	220		35–40	12–15			5
ibid.	Russar-38	*ibid.*	36	148	1:7.7						30	10	12 (25)	12 (14)	
AFA-27-T	F-3	13×18	400	31	1:4.5	B-t-l	1/100–1/200	i'ch.			20	10			80
AFA-33		30×30	100	130											
AFA-33-M	Orion-1A	*ibid.*	200	92	1:6.3	B-t-l	1/50–1/200	i'ch.			30–32	6			8
ibid.		*ibid.*	500	46		F-p	1/50–1/200								
ibid.		*ibid.*	750	32		F-p	1/50–1/200								
ibid.		*ibid.*	1,000	24		F-p	1/50–1/200								
AFA-37	Russar-29	18×18	70	122	1:6.8	B-t-l	1/50–1/120	ZhS-18	250		25–36	10–15			10
AFA-IM	Industar-4	13×18	200	56	1:4.5	B-t-l	1/200–1/400	i'ch.			30	6			70
AFA-TEU	Russar-43	18×18	140	85	1:6.8	B-t-l ar	1/65–1/480				36	18–20			
Aerofoto-opredelitel'	Nine lenses Industar-24	Nine times 6×6	105	44	1:6.5			i'ch.							
AShChAFA-2	Russar-Plasmat	24	210	60	1:3.5	0	—	i'ch.			40	15			10
ibid.	Russar-25A	*ibid.*	70	122	1:6.3	0	—	i'ch.			25	15			50
unknown	Russar-31	30×30	120	120											
ibid.	Russar-33	24×24	100	122	1:9						34–52	16	15		
ibid.	Russar-44	18×18	100	104							34	18	18	15	14
ibid.	Russar-37	*ibid.*	50	137											
ibid.	Russar-39		35								42–47				

Annotations to table 1

Column "Angular field": The angular field refers to the diagonal of the Photo except for the Shutterless AShChAFA-2 where it is valid for the width of the filmstrip.

Column "Relative aperture": The values reported by various authors are often somewhat different. In this table the best values are given assuming that the inferior ones are true for older lenses of the same type now obsolete.

Column "Shutter": "L" stands for Louvre-Shutter; "B-t-l" for Between-the-lens shutter; "f-p" for Focal plane shutter; "ar" for automatically regulated; "O" for "No shutter."

Column "Shutter speeds": According to Veselovskiĭ (1958) newer models of the AFA-TE type are equipped with shutter speeds up to 1/1000 sec. Column "Filter": "i'ch." means "interchangeable"; a particular filter such as "ZhS-18" indicates that it is a fixed part of the lens system.

Column "Resolving power, photographic": The resolving power has in general been determined by photographing a high-contrast parallel line target through a yellow filter and at maximum aperture on panchromatic film (type "10-800"). The values in brackets are valid for a radial line target.

extremely high and prevent its regular application except for sample areas.

Zaitov and T͡suprun (1962) of the MIIGAiK have constructed the prototype of a nine-lens camera, the so-called "Aerofotoopredelĭtel'," permitting one to take photographs of a size of 6×6 cm (2.4×2.4″) on three different films which run side by side. On each film photographs can be taken through a set of three lenses. As a result simultaneous photography with nine different film-filter combinations can be carried out and thus applied to solve the problem of the photographic technique most suitable for a particular interpretation purpose.

Investigations about the possibilities of electronic control of exposure move along two different lines and, consequently, have led to constructing two different devices at the T͡sNIIGAiK. On the one hand, the solution is found in the automatic regulation of the lens aperture via a photocell. This principle is realized in the automat ADO, which, according to Beli͡aev (1961), is adaptable to all types of cameras. On the other hand, a similar control is exercised on the shutter speed in the AFA-TEU camera devised by Il'in and Dervis (1962). Testing the prototype gave as a result the possible range of the exposure time as extending from 1/65 to 1/480 sec. The automatic control of exposure improves throughout the film roll the balance of the negative densities, which, therefore, tend to approximate a mean optimum value. Some practical experiments showed that the deviations of the single negative densities from the mean overall value on one film in general, did not exceed 10%. A good balance of the densities within one film is a prerequisite for a possible automation of negative and positive processes. This is important above all for the photography of high mountain terrain where high contrasts between bright snow or ice-covered areas and dark forests with heavy shadows have to be expected.

As reported by Uspenskiĭ (1961) a characteristic property of Russian wide-angle lenses is their susceptibility to a kind of hotspot phenomenon, called "podsvet" in Russian. This takes on the negatives the shape of a brandy glass or a flat iron. It is known that such effects are likely to occur on one or two negatives of nearly every run. They are obviously not of the same origin as the well-known point-of-no-shadow which is due to the natural absence of shadows at the place where the direction of the incoming sun's rays and the angle of view coincide. Uspenskiĭ was able to clear up the problem through laboratory experiments, showing that the specific constructive principle of the Russar lenses accounts for the appearance of parasitic light in the focal plane. In the case of actual air photography such light originates from objects in the terrain with a heavy direct reflection such as waterbodies. The hotspot effect appears on the negative when the source of direct reflection lies near the edge of or just outside the terrain section being photographed. This light is then falling into the lens in such a way as to be almost completely reflected on one or two of the glass surfaces and thrown into the focal-plane. The phenomenon seems to occur exclusively with lenses of the Russar type. In any case, comparative testing of Wild optics showed no similar result.

Films and Filters

Among the light-sensitive materials the conventional panchromatic film has so far been used almost exclusively for routine photography. Common is the type "10-800"[5] with a sensitivity of 800 to 1,000 GOST[6] and a resolving power of 60 to 90 lines per mm. under laboratory conditions. The type "11" distinguishes itself by a 50% decrease in sensitivity but an increase in resolving power (120 to 130 lines per mm.). Mikhailov (1959) in his article on the status of air photography in the USSR states that the comparison of Russian and American films reveals a superiority of the latter since films with the same degree of sensitivity show a higher resolution. This was in 1959, however, and in the meantime the quality of the Russian films may have been improved.

[5] For this and all following types of film discussed, see the technical data in Table 2 and the spectral sensitivity curves in Figures 1 and 2.

[6] GOST stands for "Gosudarstvennyĭ Standart" (=state standards). For the general use the sensitivity of photographic materials is expressed by the reciprocal value of the exposure time in lux sec* needed to achieve a negative density of 0.2 above fog. For the special case of aerofilms, however, the determination of the sensitivity is based on a density value of 0.85 above fog since experience shows that negatives with a mean density of this degree will deliver prints of optimum quality. The transformation of GOST values into the values of another system of sensitivity cannot give accurate figures unless the same photographic material is examined with both methods. Consequently, the values in DIN and ASA reported in table 2 must be considered as approximate only.

* Same as meter-candle second—a unit of exposure—Ed.

There exist a variety of other types of films, but they have mainly been used for pilot studies rather than for practical work. For one or the other of these films, however, a broader practical application in the near future may be predicted.

Films sensitive to infrared radiation have been produced in the Soviet Union for years. But until a couple of years ago they were seldom used for air photography as their quality was totally insufficient. Their main drawback was an instability that caused a loss of sensitivity a short time after the films had left the plant. Consequently, the Soviet film industry greatly tried to eliminate this serious defect; the infrared material produced nowadays is much better. In spite of this progress, infrared air photography is still not very popular, because for a few years it has been rivaled by a new kind of film, the so-called "spectrozonal" color film, from which black-and-white contact prints showing the typical infrared effect can also be obtained. Nevertheless, the application of the infrared film is recommended by various authors for forestry and other purposes. Rychkov (1959) reports the suitability of the infrared summer photograph for the survey of agricultural regions. Vinogradova (1955) suggests its utilization also for photography in dry areas for the reason that differences in soil moisture—which are of paramount importance for the geomorphological and pedological interpretation in such regions—are recorded in an exaggerated fashion. The infrared material is labelled as "I-760" and has a sensitivity of 100 to 150 GOST if used in the usual combination with a red filter.[7]

It may be surprising that the field of application of the black-and-white orthochromatic film is probably to be broadened. These are the prospects according to several authors who have obtained successful results with regard to different interpretation problems. The outstanding feature of the orthochromatic material is its increased sensitivity to green light as compared with the panchromatic film. Its use, therefore, is advisable in all those cases where green light plays an essential part in reflecion. This is true for all types of vegetation. The orthochromatic photograph taken over forested areas in summer shows increased tonal contrasts between single tree species, especially between pine (*Pinus silvestris*) and birch (*Betula pubescens* and *Bverrucosa*). The distinguishability of these two species, however, is of great importance for forest inventory purposes (Berezin and Kharin 1960). Pronin (1949) recommends the orthochromatic film also for spring photography since during the period when the trees are breaking into leaf, contrasts in the green part of the spectrum can be observed. On autumn photographs the interpretation prospects are about the same for both the orthochromatic and the panchromatic material.

Orthochromatic photographs have also proved to be excellent for the record of underwater features when photographed through shallow water because the transmission through the water is the highest for green light. Comparative experimental sorties carried out over the Caspian Sea with orthochromatic and panchromatic film showed the superiority of the former if used in combination with a yellow filter. These findings may be of importance for geological investigations correlated with oil prosecting (Kal'ko 1958). The orthochromatic film carries the designation "RF-3" and shows similar characteristics to the panchromatic film "10–800" with respect to sensitivity and resolving power.

The normal three-layer color film has not been used very widely up to now. This is due to the general well-known disadvantages of this type of film limiting its application; i.e. the relatively low sensitivity and the susceptibility to blue haze light. The sensitivity of the Russian color films "T͡sN-1" and "T͡sN-3" amounts to 50 and 150 GOST, respectively. In principle, however, a color film taken at favorable conditions and with the correct exposure may convey much more information than a black-and-white one, since the range of possible color tones is much larger than one of gray tones. As a matter of fact, some of the authors such as Berezin (1955) and Vinogradova (1955) emphasize a number of points that plead for the superiority of the color film:

(1) On summer photographs the separation of deciduous and coniferous trees is possible with much greater accuracy;
(2) Visibility through the crowns is increased, i.e., one can recognize details of the second tree stratum, of the young growth, and of the herb stratum owing to the pronounced color contrasts between trees, undergrowth, and shadows;

[7] For the filters mentioned in this paper see the spectral transmission curves in Figure 3.

Table 2

Technical Data of Soviet Aerofilms

Compiled from Belov (1959), Belov and Berezin (1958), Iordanskiĭ (1955), Mikhailov (1961), Solov'ev (1961), and Tsyganov (1960)

Type of Film	*Designation*	*Number of sens. layers*	*Filters used*	*Sensitivity*			*Laboratory resolving power*	*Gamma at "optimum development"*
				$Sd_{0.85}$ *GOST*	*Approximate values of* *DIN*	*ASA*		
Panchromatic	10–800	1	ZhS-18	800–1,000	28	400	60–90	1.7–2.0
ibid.	11	1	ZhS-18	400–500	25	200	120–130	
Orthochromatic	RF-3	1	ZhS-18	800–1,000	28	400	65–80	1.6
Infrared	I-760	1	KS-14	100–150*	18–20*	40–64*		2.0
Paninfrachromatic	TsN-1	1	KS-14	90*	18*	40*		
Color, negative		3	JS-3	50	15	20	35–50	0.65–0.80
ibid.	TsN-3	3	JS-3	150	20	64		1.0
Spectrozonal, neg.	SN-2	2	ZhS-18	200–300*	21–23*	80–125*	60–70	1.5–2.0
			OS-14					1.5–2.0
			KS-14	50–70*	15–17*	20–32*		1.5–2.0
Spectrozonal, pos.	SP-1	2	ZhS-18	85*	17–18*	32–40*		

Annotations to table 2

Column "Sensitivity". An asterisk indicates that the given value refers to the combination of film and filter. The value for the paninfrachromatic material is an estimation made from the spectral sensitivity curve (fig. 1).

Column "Gamma". "Optimum development" usually is reached at a fog density of 0.3 to 0.35.

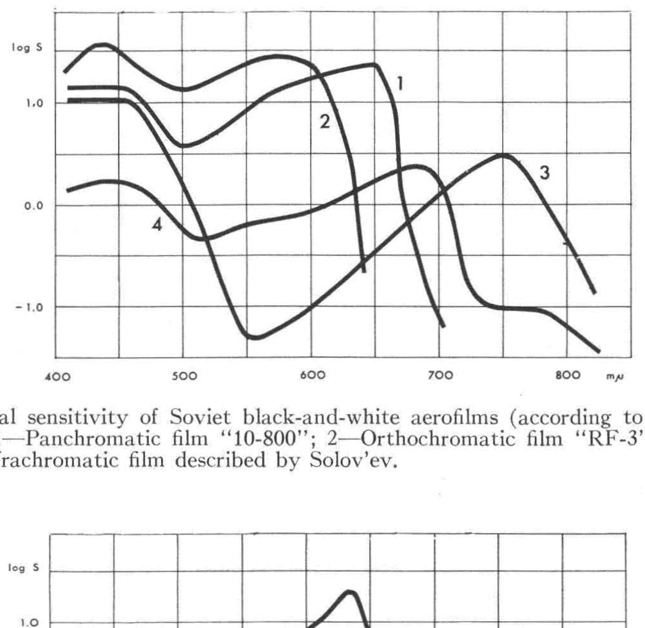


Fig. 1. Spectral sensitivity of Soviet black-and-white aerofilms (according to Belov (1959) and Solov'ev (1961)). 1—Panchromatic film "10-800"; 2—Orthochromatic film "RF-3"; 3—Infrared film "I-760"; 4—Paninfrachromatic film described by Solov'ev.

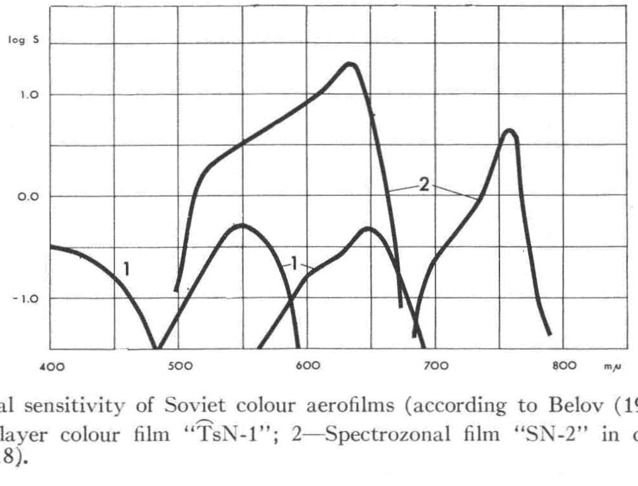


Fig. 2. Spectral sensitivity of Soviet colour aerofilms (according to Belov (1959) and Mikhailov (1961)). 1—Three-layer colour film "TsN-1"; 2—Spectrozonal film "SN-2" in combination with a yellow filter (ZhS-18).

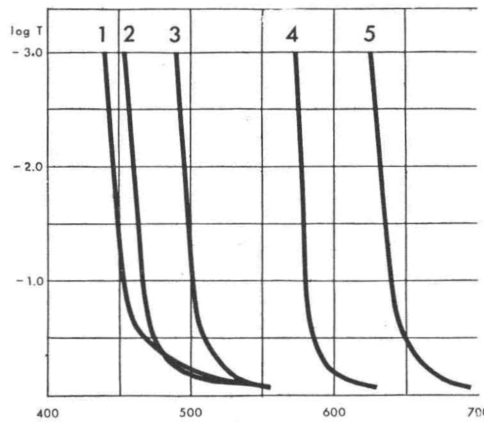


FIG. 3. Spectral transmission of Soviet filters used in air photography (according to Belov (1959). 1—Light-yellow filter "ZhS-12"; 2—Medium-yellow filter "ZhS-14"; 3—Dark-yellow filter "ZhS-18"; 4—Orange filter "OS-14"; 5—Red filter "KS-14."

(3) Spots with dead trees and wind damages stand out very well;
(4) Small rivers crossing forested areas are much more easily identified than on black-and-white photographs;
(5) In high mountain areas rock outcrops, screes, dwarf-shrubs, and bushes can be separated without difficulties.

On the other hand, the same authors cite also some drawbacks. For example, the color photograph does not allow the distinction between dry and swampy meadows since both of them appear with the same tone.

Of much more importance is a two-layer color film, the so-called "spectrozonal" film, which renders the colors in an unnatural way and in this respect may be compared with the American Camouflage Detection film. It has been developed at the Scientific Research Institute for Cinematography and Photography ("Nauchno-Issledovatel'skiĭ Kinofoto institut" = NIKFI) under the direction of Iordanskiĭ. The upper layer is sensitive to infrared light and after development turns out blue-green; the lower layer is sensitive to visible light and becomes magenta. In most cases contact prints are made on the common color paper, the "Fototsvet," with three layers sensitive to yellow, green, and red, respectively. As a result objects with strong reflection in the infrared show on the positive red, orange, or yellow tones, while objects with a weak remission in this part of the spectrum appear as green and blue-green tones. Some examples of the rendering of colors on the spectrozonal three-layer positives are assembled in Table 3.

A salient feature of this type of photography is its much lower susceptibility to haze effects. There is no reason preventing the utilization of a filter for the elimination of the blue light since the appearing colors are unnatural anyhow. Therefore, it is possible to take the spectrozonal photographs from higher flying altitudes than is the case for conventional color photography. With the selection of one of the filters from a set ranging between yellow and red it is even possible to control the formation of unnatural color effects to a certain extent. A further advantage of the spectrozonal film is the increased tolerance with regard to the allowable loss of illumination towards the edges in the focal-plane. Whereas for the normal color film an illuminance under 75% causes a noticeable deficiency, the corresponding marginal value for the spectrozonal material may be as low as 30%. An underexposure on the three-layer color film results in a serious deformation of color tones and, consequently, the use of wide-angle lenses for the common color photography is impossible.

The input in terms of time for the laboratory treatment of the spectrozonal film is three to four times higher than for the black-and-white material but even so is two times lower than for the three-layer color film. In terms of cost the spectrozonal photography is only 10 to 12% more expensive than the black-and-white one, although the costs for the film alone are 1.5 times and for the color paper alone 9 times higher. The reason for this is that the flight itself accounts for the main share of the costs, namely 85%. Moreover, the necessary field-work can be reduced considerably with spectrozonal photographs which is still more important as expenses for the field-work are generally three to four times higher than for the actual air photography. From the financial point-of-view, therefore, there is no reason why the spectrozonal photography should not be used much more in the future.

Some characteristics of the spectrozonal photograph pertinent to forestry and geobotanical interpretation are listed here (according to Belov (1959) et al.):

(1) The spectrozonal air photograph combines the advantages of both the infrared and the normal color material. This enables the interpreter to distinguish

TABLE 3

COLOR TONES OF DIFFERENT OBJECTS ON SPECTROZONAL AIR PHOTOGRAPHS TAKEN WITH SN-2 FILM AND ORANGE FILTER (OS-14) AND PRINTED ON THREE-LAYER PAPER OF THE "FOTOTSVET" TYPE

Compiled from Berezin and Kharin (1960), Kharin (1960), and Mikhailov (1961)

Object	*Color tones*
Deciduous forest in general	orange-red, gray-brown, coffee-brown, purple
Beech	orange-coffeebrown, light brown
Hornbeam	*ibid*
Oak	yellowish-brown, greenish-graybrown, coffee-brown to gray-brown; darker than other deciduous trees
Birch	greenish-yellow, light orange, yellow-orange
Aspen	brownish-red, light orange, yellow-orange
Coniferous forest in general	blue-green, dark green
Spruce	dark blue-green, dark green
Fir	dark green
Pine	green
Larch	orange, light orange; similar to deciduous trees
Clearings	yellow-green
Dead trees	crude blue, greenish-blue
Bogs and tundra in general	yellow, light yellow-green, light green, dark green, etc.
High bog	yellow
Grass marsh	yellow-green
Rush	orange-graybrown
Dwarf birch	greenish-brown
Moss	dark green
Lichen	light green
Meadow	yellow-orange, yellow-graybrown, red; depending on phenological stage and degree of cover
Pasture	dull brown
Crops	light green, graybrown-green; depending on method of cultivation, soil moisture, and stage of development
Water	dark blue, dark blue-green
Black-top road	light yellow, graybrown-yellow; depending on soil type
Freshly excavated material	light yellow
Sandstone	brownish-gray, grayish-yellow

easily between deciduous and coniferous trees;

(2) The larch (*Larix sibirica* and *L. dahurica*) is the only exception to this rule since its color records similarly to that of the deciduous trees. This, of course, is a serious drawback for air photography in Siberia, where birch and larch often occur in mixed stands;

(3) On the other hand, the also important and otherwise difficult separation of pine and birch can be attained with ease;

(4) The tonal contrasts between species within the main groups, i.e., deciduous and coniferous trees, respectively, are relatively small. Different species appearing within the same photograph may be distinguishable, but their identification is almost impossible if they occur on different photographs of even the same run;

(5) Of specific importance for forestry is the spectrozonal film because dead trees stand out with a crude blue or a greenish-blue tone. Damaged areas, therefore, can be mapped accurately. As a matter of fact, the spectrozonal photography has successfully been used for surveying the areas infected by the Siberian silk-moth (Dendrolimus sibiricus).

For printing from spectrozonal negatives a special spectrozonal paper, called "SB-2", with two layers, the one sensitive to blue-green and the other to red, is available. This method results in colors which differ considerably from the appearance on the "Fotot͡svet" paper previously discussed. Coniferous forest records in a brownish dark-gray, deciduous trees show up in bluish green colors. The use of the SB-2 paper, however, is not very popular except for the location of damage in forests, since dead trees are rendered in a crude red and their appearance is for the interpreter still more striking than on the "Fotot͡svet" prints. The reason for the rare use of the two-layer paper is that in general the range of possible color tones on the three-layer positives is much wider.

In a way analogous to the two kinds of paper positives, prints can also be made on either three-layer or two-layer film. This method, however, is not very often used.

What has been said about the spectrozonal film so far is true for the material labelled as "SN-2" the sensitivity of which Belov (1959) has reported to be 150 GOST if used in combination with a red filter. The production of other types of spectrozonal films with a different combination of emulsions and, therefore, still different color effects would be possible. Actually, there has been much experimentation with films called "SN-3" (sensitive to blue and red) and "SN-4" (sensitive to green and red), but without getting encouraging results. A material affected by green and infrared light would surely be promising, but such a film has not yet been produced and examined.

The SN-2 film may also be superior for geological investigations as long as the vegetation cover serves as an indicator of the kind of bedrock and of structural characteristics (Bakhvalov 1960). On the other hand, its application for photography of desert areas with sparse vegetation is not to be recommended. Here the conventional color film will meet the needs much better since the identification of rock and soil types can be performed more easily on the basis of natural color tones. Likewise, the three-layer color film has advantages over the spectrozonal one in mountainous terrain. As a whole, Belov (1959) believes in a much wider practical application of spectrozonal materials in the near future.

As the last one among the sensitive materials there may be mentioned a type of film which has been described by Solov'ev (1961) as "paninfrachromatic" film. It is designed to combine the advantages and to eliminate the disadvantages of both the panchromatic and the infrared film for the photography of vegetation complexes. The basic idea is the following: deciduous forest on panchromatic photographs records too dark since the sensitivity of the negative material extends as far as a wave-length of 660 to 680 mμ, where the absorption of green plants is very pronounced On the other hand, the same forest shows up too bright on infrared prints. These facts suggest the production of a material that combines a sensitivity for red and for near-infrared radiation. As a result, the areas covered with deciduous forest are not under- or overexposed any longer, but appear in an optimum range of the gray tone scale. This means that different kinds of green will be rendered by different shades of gray. According to Solov'ev good results can be obtained if the film is used together with a red filter whose absorption edge lies at 640 mμ. The photographs thus taken will probably give a similar effect to the well-known infrared minus-blue photography. It must be taken into account, however, that this paninfrachromatic material differs from the conventional infrared film by a higher sensitivity to red radiation.

References

1. Bakhvalov, V. M. 1960, "Metodika spektrozonal'noĭ aerofotos" emki na plenke SN-2 i ee kharakteristika dli͡a deshifrirovanii͡a aerosnimkov pri poiskakh korennykh mestorozhdeniĭ almazov" (The methodology of spectrozonal air photography on SN-2 film and its characteristics for prospecting primary beds of diamonds by means of photo interpretation), *Primenenie aerometodov pri poiskakh korennykh mestorozhdeniĭ almazov*, pp. 55–65, Izd.AN, Moscow/Leningrad.
2. Beli͡aev, N. A. 1961, "Pribor avtomaticheskogo diafragmirovanii͡a ob"ektiva aerokamery" (A device for the automatic regulation of aperture of air photo lenses), *Trudy T͡sNIIGAiK*, no. 142, pp. 51–68, Geodezizdat, Moscow.
3. Belov, S. V. 1959, "*Aerofotos"emka lesov*" (Air photography of forests), Izd.AN, Moscow/Leningrad.
4. Belov, S. V. and Berezin, A. M. 1958, "Znachenie usloviĭ aerofotografirovanii͡a i razlichnykh tipov aeroplenok dli͡a izuchenii͡a lesov" ("The importance of photographic conditions and different types of aerofilms for the survey of forests"), *Trudy LAER*, vol. 6, pp. 146–175, Izd.AN, Moscow/Leningrad.
5. Berezin, A. M. 1955, "Opyt deshifrirvanii͡a lesov taezhnoĭ zony na t͡svetnykh aerofotosnimkakh" ("An attempt to interpret forests of the Taiga zone on colour photographs"), *Geograficheskiĭ Sbornik*, vol. 7, pp. 128–139, Izd.AN, Moscow/Leningrad.
6. Berezin, A. M. 1961, "Vlii͡anie usloviĭ aerofotos"emki na dostovernost' deshifrirovanii͡a lesov na aerosnimkahk" ("The influence of photographic conditions on the accuracy of forest air photo interpretation"), *Ispol'zovanie aerometodov pri issledovanii prirodnykh resursov*, pp. 35–40, Izd.AN, Moscow/Leningrad.
7. Berezin, A. M. and Kharin, N. G. 1960, "Deshifrirovanie po aerosnimkam lesov l'vovskoĭ oblasti i Prikarpat'ia" ("Air photo inter-

pretation of forests in the region of L'vov [Lemberg] and the piedmont of the Carpathian Mountains"), *Trudy LAER*, vol. 10, pp. 123–133, Izd.AN, Moscow/Leningrad.

8. Gerasimova, O. A. 1961, "Issledovanie aeros"emochnykh ob"ektivov, prednaznachennykh dli͡a topograficheskoĭ s"emki" ("An investigation of air photography lenses designed for topographical surveys"), *Trudy TsNIIGAiK*, no. 142, pp. 5–31, Geodezizdat, Moscow.
9. Gospodinov, G. V. 1961, "*Deshifrirovanie aerosnimkov*" ("Air photo interpretation"). Izd.Moskovskogo Universiteta, Moscow.
10. Il'in, V. B. and Dervis, V. D. 1962, "Aerofotoapparat AFA-TEU i ego ispytanii͡a" ("The air photo camera AFA-TEU and its testing"), *Trudy TsNIIGAiK*, no. 146, pp. 3–15, Geodezizdat, Moscow.
11. Ĭordanskiĭ, A. N. 1955, "Spektrozonal'nai͡a aeroplenka" ("The spectrozonal aerofilm"), *Trudy TsNIIGAiK*, no. 107, Geodezizdat, Moscow.
12. Kal'ko, A. G. 1958, "Aerofotos"emka morskogo dna" ("Air photography of the sea bottom"), *Aerogeologicheskai͡a s"emka melkovodnykh zon Kaspiĭskogo mori͡a*, pp. 133–137, Izd.AN, Moscow/Leningrad.
13. Kharin, N. G. 1960, "Aerometody izuchenii͡a tipov lesa" ("Aeromethods of investigating forests"), *Trudy LAER*, vol. 9, pp. 276–281, Izd.AN, Moscow/Leningrad.
14. Krinov, E. L. 1947, "*Spektral'nai͡a otrazhatel'nai͡a sposobnost' prirodnykh obrazovaniĭ*," Izd.AN, Moscow/Leningrad; Translation into English by G. Belkov, "Spectral reflectance properties of natural formations," Natural Research Council of Canada, Techn. Transl. no. 439, Ottawa, 1953.
15. Mikhailov, V. Ia͡. 1959, "Sovremennoe sostoi͡anie i blizhaishie perspektivy razvitii͡a nauchnykh rabot v aerofotografii" ("The present status of the scientific work on air photography and the prospects for its further development"), *Trudy LAER*, vol. 7, pp. 10–18, Izd.AN, Moscow/Leningrad.
16. Mikhailov, V. Ia͡. 1961, "The use of colour sensitive films in aerial photography in USSR," *Photogrammetria*, vol. 17, no. 3, pp. 99–104, Amsterdam.
17. Pestrecov, K. 1954, "Notes on Russian photogrammetric optics," PHOTOGRAMMETRIC ENGINEERING, vol. XX, no. 3, pp. 488–492.
18 Pronin, A. K. 1949, "Izuchenie rastitel'nosti putem aerofotografirovanii͡a v raznykh zonakh spektra" ("The investigation of vegetation by means of air photography in different zones of the spectrum), *Trudy LAER*, vol. 1, pp. 69–91, Izd.AN, Moscow/Leningrad.
19. Rusinov, M. M. 1959, "Noveishai͡a shirokougol'nai͡a aerofotos"emochnai͡a optika i blizhaishie perspektivy ee razvitii͡a" ("Modern wide-angle air photography optics and the prospects for their further development"), *Trudy LAER*, vol. 7, pp. 114–120, Izd.AN, Moscow/Leningrad.
20. Rychkov, N. N. 1959, "Itogi primenenii͡a aerofotos"emki dli͡a nuzhd sel'skogo khozi͡aistva SSSR za 1931–1956 gg." ("Results of air photo application for the needs of the agriculture in the USSR in the years 1931 to 1956"), *Trudy LAER*, vol. 7, pp. 265–270, Izd.AN, Moscow/Leningrad.
21. Shershen, A. I. 1958, "*Aerofotos"emka*," Geodezizdat, Moscow; Translation into English by Y. Rosenberg, "Aerial Photography," Israel Program for Scientific Translations, Jerusalem, 1961.
22. Smirnov, A. Ia. 1960, "K voprosu o primenenii spektrozonal'noi plenki SN-2 dli͡a aerofotos"emki lesa" ("The question of utilizing the spectrozonal film SN-2 for the air photography of forests"), *Trudy LAER*, vol. 9, pp. 331–340, Izd.AN, Moscow/Leningrad.
23. Solov'ev, M. S. 1961, "O primenenii paninfrakhromaticheskikh materialov v aerofotos"emke" ("On the application of paninfrachromatic materials in air photography"), *Trudy TsNIIGAiK*, no. 142, pp. 165–171, Geodezizdat, Moscow.
24. Troll, C. 1943, "Fortschritte der wissenschaftlichen Luftbildforschung," *Zeitschr. der Gesellschaft für Erdkunde zu Berlin*, no. 7/10, pp. 2–36.
25. T͡syganov, M. N. 1960, "*Osnovy fotografii i aerofotografii*," ("The principles of photography and air photography"), Geodezizdat, Moscow.
26. Uspenskiĭ, A. N. 1961, "Issledovanie parazitnogo sveta, popadai͡uschego v fokal'nui͡u ploskost' shirokougol'nykh aerofotoapparatov" ("The investigation of parasitic light affecting the focal plane of wide-angle cameras"), *Trudy TsNIIGAiK*, no. 142, pp. 33–50, Geodezizdat, Moscow.
27. Veselovskiĭ, N. N. 1958, "*Aerofototopografii͡a*" (Aerophototopography), Geodezizdat, Moscow.
28. Vinogradova, A. I. 1955, "Izuchenie rastitel'nosti i pochv s pomoshch'iu aerofotografirovanii͡a v razlichnykh zonakh spektra" (Surveying vegetation and soils by means of air photography in different parts of the spectrum), *Geograficheskiĭ Sbornik*, vol. 7, pp. 59–74, Izd.AN, Moscow/Leningrad.
29. Zaitov, I. R. and T͡suprun, S. I. 1962, "Aerofotoapparat dli͡a vybora tipa plenki" (An air photo camera for the determination of the suitable film type), *Geodezii͡a i Aerofotos"emka*, no. 3, pp. 77–81, Moscow.

Abbreviations used in the list of references:

Geodezizdat = Izdatel'stvo geodezicheskoĭ literatury (Publishing house for geodetic literature)
Izd.AN = Izdatel'stvo Akademii Nauk (Publishing house of the Academy of Sciences)
Trudy LAER = Trudy Laboratorii Aerometodov (Research Series of the Laboratory for Aeromethods)
Trudy T͡sNIIGAiK = Trudy T͡sentral'nogo Nauchno-Issledovatel'skogo Instituta Geodezii, Aeros"emki i Kartografii (Research Series of the Central Scientific Research Institute for Geodesy, Air Photography, and Cartography).