COMPARATIVE FEATURES OF LORAN AND CONSOL LONG-RANGE NAVIGATIONAL AIDS

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(From « Navigation », Paris, Vol. III, No. 10, April 1955)

INTRODUCTION

It may seem surprising to a technician or a navigator that one should venture to compare two navigational systems which in fact bear no comparison. This event nevertheless occurred at the last meeting of I.C.A.O. The arguments there advanced were favourable to Consol, to the technicians' great surprise. The following article is a summary of the opinions presented by airmen at the International Airlines Navigators Council. The technical developments which were described in appendixes have not been reproduced here.

THE AIRBORNE RECEIVER ASPECT

The basic principles of the Loran and Consol systems are too well known to warrant their being mentioned here. In general, explanations are given from the ground station aspect, accompanied by various diagrams. We believe that this should be completed from the airborne-receiver aspect, as considered from the point of view of the receiving aerial remote from the station. This approach makes no reference to the transmitter on the ground, which is of minor interest to the user, but only to the signals received which enable determination of a position line.

Case of Consol.

With respect to a receiver placed in the station's field, Consol operates as a highly-directional single-beam radio beacon actuated by two types of motion:

(*a*) a rapid oscillation on either side of an axis (rapid rate of phase change at the transmitter);

(*b*) a slow rotation similar to that of a rotating radio beacon (slow rate of phase change at the transmitter).

A receiving antenna will therefore be affected by a series of impulses which follow a dot and dash rhythm. In the absence of such impulses, *no signal is applied to the receiving antenna.* This antenna, during transmission, is subjected to three signals, sent out simultaneously by three antennas operating on different phases. Their combination supplies the oscillating diagram provided the differences in phase between the transmitting aerials are reproduced in the zone of reception. Accuracy therefore depends on the phase rate of the waves at the moment of propagation. The angle subtended at the receiving aerial by the three transmitting antennas is always very small.

Case of Loran.

In the case of a receiver located in the field of a Loran chain, Loran operates as an omni-directional transmitter radiating two distinct impulses supplying information as to the position line. A receiving antenna will therefore receive an initial series of waves corresponding to the first impulse, and then a second series of waves following a time interval proportional to its position with respect to the chain. In the absence of any impulse, *no signal is applied to the receiving antenna*. As measurement consists in determining the time elapsing between the two impulses, the airborne equipment will consist of a single receiver and an electronic chronometer. The phase differences in the carrier waves arriving at the antenna have no effect on the accuracy of indications, which is solely dependent on the speed of the group at the time of propagation. The angle at the receiving aerial subtended by the stations may be large and varies according to the position in relation to the baseline.

We shall endeavour to compare these two systems on the basis of the I.C.A.O's classifications, i.e.:

— the range obtained;

— the accuracy obtained;

— the possibilities of interference; and

— the ease of use.

MAXIMUM AND STANDARD RANGES

A distinction should be made between the ranges obtained exceptionally by trained personnel under unusual propagation conditions, requiring a high degree of selection on the part of the operator (rejection of 30 % of readings), and the standard ranges which can be obtained at the 95 % probability level.

The maximum ranges obtained with Loran, such as in the 1H4 and 1H7 chains, are the following:

(*a*) Dakar - Recife;

(*b*) Santa-Maria - Fort-de-France;

(*c*) Dakar - Paramaribo;

(*d*) Algiers - Niamey;

(*e*) Tripoli - Fort-Lamy.

These correspond to ranges of more than 3,000 n.m. with an average accuracy, measured over the ground, of 8 to 10 n.m.. Communication was established by means of two, three or four hops over the E-layer. According to a summary of existing data, *the standard ranges* for Loran are the following :

LORAN					
DIRECT WAVES				REFLECTED WAVES	
OVER GROUND		OVER SEA		OVER GROUND	OVER SEA
Day	Night	Day	Night		
70 n.m. Low alt. 150 n.m. High alt.	300 n.m.	600 n.m.	450 n.m.	550 n.m.	1,400 n.m.

The maximum ranges obtained with Consol, such as from the Ploneis station, involve 2/5ths reception at the following points:

(*a*) Prince Christian;

(*b*) 45° W. - 51° N. on the great circle arc from Shannon to Gander; and

(c) Shark (exceptionally).

These correspond to ranges of about 1,700 n.m. and exceptionally 1,900 n.m., with an accuracy of from 10 to 15 n.m. when a fairly large number of readings are taken. Such ranges were obtained by means of one or two hops over the E-layer. According to a summary of existing data, *the standard ranges* for Consol are the following:

CONSOL					
DIRECT WAVES				REFLECTED WAVES	
OVER GROUND		OVER SEA		OVER GROUND	OVER SEA
Day	Night	Day	Night		
750 n.m.	400 n.m.	950 n.m.	500 n.m.	From 1,000 to 1,300 n.m.	From 1,300 to 1,500 n.m.

TYPES OF POWER USED SIGNAL-TO-NOISE RATIO

Without discussing the ground station aspect of the question, it is of interest to observe the level of signals in the receiving antenna. The higher this level in relation to a given amount of interference, the better the signal-to-noise ratio, which facilitates reading and results in increased accuracy of information.

A standard Consol transmitter operating on pure continuous waves has an *output power* of 2 kW distributed at the foot of each antenna by feeder lines. The centre aerial radiates with an efficiency of approximately 15 %. *The radiated power* therefore approximates one half of a kilowatt (see *Technical Paper* n° 1, United Kingdom, PICAO, 1946). When considering transmission in the 300 kilocycle band, the strength of reception (or signal level) decreases by about 50 % every 60 n.m. beyond a range of 160 n.m. (as regards the direct wave). Reducing the noise level through the operation of a band pass filter enables the signal noise ratio to be increased by 10 db., which may increase the range by about 150 n.m. Should one desire to raise the signal noise ratio by another 10 db., it would be necessary to increase the output power of the transmitter by about 20 kW.

A Loran transmitter operating on an impulse system has an *output power* of 200 W.; and the 40-microsecond-wide impulses transmitted at the rate of 25 or 33 per second have a peak power of 100 kW. The antenna operates at approximately 75 % efficiency. The attenuation in the case of a horizontally-propagated direct wave is about 10 db. per 85 n.m. The maximum sensitivity of the receivers used being approximately 2 microvolts per metre in the case of Loran as well as Consol, it is clear that, under equal interference conditions, *the signal-to-noise ratio of Loran will be higher than that of Consol* (at an equivalent distance). And this in spite of the fact that it is impossible to reduce the band pass of the Loran receiver below 70 kc/s. at 6 db., lest the impulses received be distorted.

SPEED OF INTERPRETATION OF INFORMATION

The factor sought in defining the accuracy of a navigational system is the distance to be assigned between the two parallel position lines most likely to limit one's position. The intersection of two measurements defines the zone of uncertainty whose side is twice the mean error of the measurement. This concept of mean error is useful to know when plotting the position lines on charts, i.e., *immediately after the reading*. When reading a Loran display, accuracy depends on the *geometrical pattern* of the leading edge of the matched pulses. The observer may immediately and with no great training assess the value of such measurements. During Consol signal detection, the passage of the equisignal informs an experienced operator as to the value of the information supplied, but generally the number of signals received must be counted and the operation repeated several times in order to establish a mean, and this requires several minutes. (Use of an automatic counting device will not alter matters, as the device will have to « register » during several minutes). In any case, the speed of measurement interpretation is higher in Loran than in Consol.

SYSTEMATIC ERROR IN A LORAN MEASUREMENT

The synchronization of Loran stations is of such stability that a maximum error of 1 μs may be accepted in impulse transmission (including Slave Station delay). The airborne receiver enables readings to be made to within 1 μs. Statistical trials made by the Electronic Sub-Division Advisory Group on Air Navigation at Wright-Field in 1946 show that an experienced operator may take readings to within 0.5 μs. For practical purposes, it is wise to assume that an error of 2.44 μs is met with in 90 % of cases. These values applied when obtaining a position line appear as a shift in the branch of the hyperbola in miles per μs., which varies according to the receiver's distance from the station and its position in the zone. This value, which is a purely geometrical one, may be computed. Thus, 1 μs on the baseline corresponds to 0.093 miles or 492 feet; an error of 2.44 μs produces under such conditions a shift of 1,200 feet or 0.23 miles. The locus of constant error is a circle drawn through the two stations. If one of these curves is taken as the limit of error, it will readily appear that the area covered increases with the length of the baseline. In other words, the error depends on the angle at the receiver subtended by the baseline. When siting the stations, it is well to bear in mind that a long baseline will supply more accurate information.

LIMIT OF ACCURACY IN A CONSOL MEASUREMENT

The factor which determines accuracy is the dot and dash count. The error introduced depends on the speed of rotation of the equisignal, which is another way of defining the angle a the receiver subtended by the baseline. If the aerials are placed farther apart, thus increasing the baseline, the number of lobes will increase and each lobe will be located in a smaller sector. The oscillating pattern « as seen from the receiver » will be more directive. For reasons governing zone identification (at an average distance), the sectors cannot be smaller than 10°, which corresponds to a wave length distance of 2.88 between each ground aerial. Whereas in Loran the limit of accuracy depends solely on the length of the baseline (maximum daylight range : 600 n.m.), Consol has reached its maximum efficiency with the distance at present used between aerials.

Errors in the Consol signal count are due to :

(a) signals « lost » during passage of the equisignal and covered by the latter;

(b) the ease with which the passage of the equisignal may be evaluated.

These two conditions cannot be fulfilled simultaneously owing to the principle of the pattern: where (b) is involved, the power radiated by the transmitter during passage of the equisignal, or, more accurately, the phasing of the three signals upon arrival at the receiving antenna, results in a weaker signal than during the separate passage of either the dot or dash sector. In order to increase reception level during the equisignal period, the dot and dash lobes should intersect near their apex, thus requiring a high current ratio between the centre and end aerials. Moreover, in order that a minimum number of signals be lost during the equisignal period [condition (a)], the level of the dot and dash signals must be rapidly increased immediately thereafter to enable their being detected against the background noise. This can only be accomplished by reducing the current ratio between the centre and end aerials. The compromise thus required further limits the possibilities of improving Consol accuracy. The result of these compromises is an average « loss » of from three to four signals, which by means of an arbitrary even distribution in the dot and dash sectors, brings the error down to one or two signals. As the sectors have a width of 10° and consist of 60 signals, the maximum theoretical accuracy achieved is one-sixth to one-third degree. As the lobes become wider in a direction away from the normal to the aerial array, accuracy decreases and reaches 0,6° at an angle of 60°. Accuracy decreases according to a more or less parabolic law. A curve enables the error to be expressed in terms of the D.R. Along the aerial baseline extensions, the signals are still received sharply, but the error increases considerably. As the equisignal shifts at a high rate of speed, a small error in the signal count results in a sizeable error in positional information; the observer must accordingly decide for himself when to stop measurements. Accuracy is closely linked with the value of D.R. and the operator's interpretation. In Loran, on the other hand, accuracy is determined by percentages of distance without ever reaching a highly critical stage.

INFLUENCE OF REFLECTED WAVES

The frequency band on which Loran operates (2 mc/s) enables space-wave propagation to take place. The use of such reflected waves introduces a source of error at the time of measurement. These errors are due to the fact that the paths after reflection do not have the same length relationships as the direct wave paths. These errors, which are zero for the bisector of the baseline, are maximum in the vicinity of either of the two transmitters. They decrease in a direction away from the stations and disappear altogether at long ranges. The errors are shown on Loran charts and may be partially corrected (correction values should vary, since the reflected propagation paths are irregular).

As the travel time of the direct waves and reflected waves is different, selection on the display is immediate (except in certain cases of superposition after multiple reflection on the E- and F-layers). In the case of Consol, selection is more difficult. Although Consol operates on a fairly low frequency band (200/300 kc/s), reflected waves likewise exist, giving rise to three zones of operation :

(a) Zones where reflected waves only exist;

(b) Zones where both direct and reflected waves exist; and

(c) Zones where direct waves only exist.

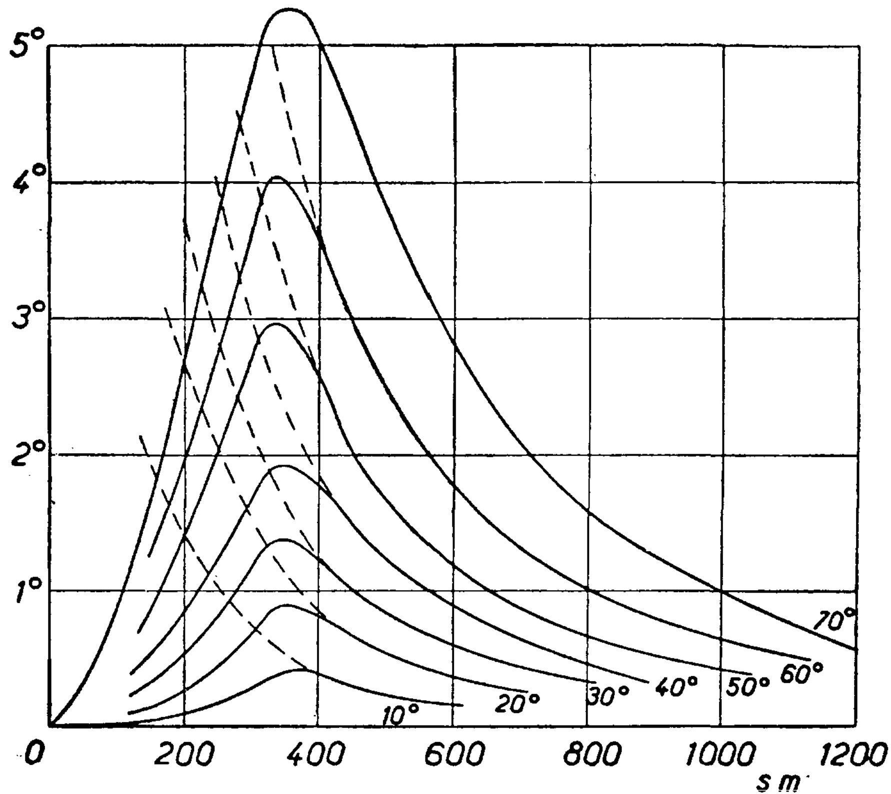

Fig. 1.
Correction curves for use of sky waves at night *over sea* in Consol system.

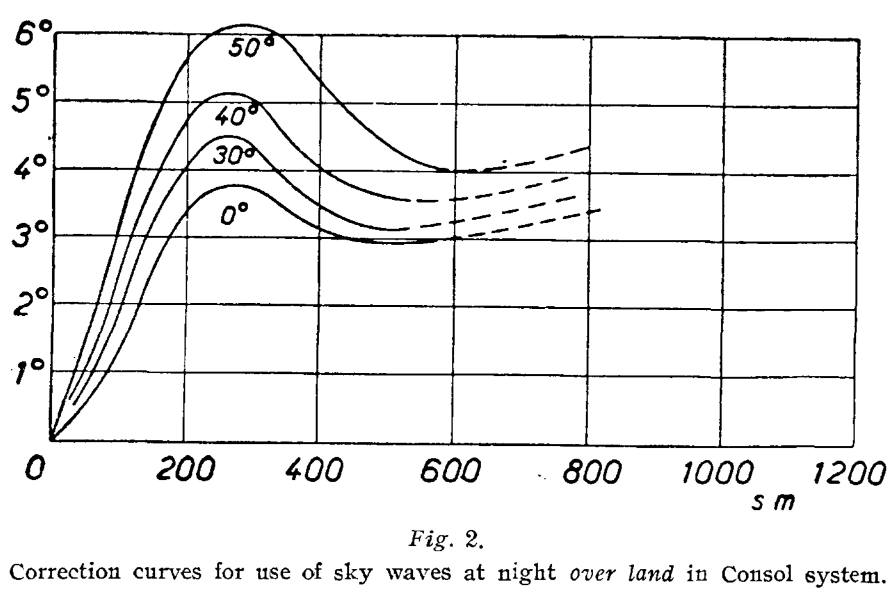

Fig. 2.
Correction curves for use of sky waves at night *over land* in Consol system.

In Zone (a), after a single hop over the E-layer, the waves from the three aerials may be assumed to have followed a single path (the length of the baseline being short). From the accuracy aspect, the conditions found in Zone (c) then prevail. Assuming that the reflection on the ionized layers does not change the great circle path, the error is given by :

$$d\,\Phi = (1 - \cos A)\tan\Phi,$$

where Φ is the angle with reference to the bisector of the line of aerials and A is the angle of incidence of the reflected wave on its return to earth. Taking 90 kilometres as the height of the E-layer, the error may be seen as reaching maximum at a range of about 400 n.m. and cancels out when this range increases. The error also increases in a direction away from the bisector. In Zone (b), accuracy is dependent on the ratio between the respective levels of the direct and reflected waves, maximum error occuring when both levels are equal. The receiving antenna then receives six signals of different phase (three from the direct wave and three from the reflected wave). The resultant signal may take on an infinite number of values according to the relative amplitude and polarization of each of the six signals. From the practical aspect, no measurement is possible in the majority of cases, since the observer detects a jumble of signals (ten dots, six dashes, eight dots, fifteen dashes, an equisignal, four dots, equisignal, twelve dashes, and so on). When phasing conditions are less poor, the operator manages to detect a consistent signal count, but the passage of the equisignal is difficult to interpret owing to the presence in the background of signals at a lower level. Only considerable aural experience on the part of the operator enables the signals to be read under such conditions, and even then interpretation is very uncertain (erratic signals may combine with a consistent group of sixty signals). The errors in this zone, which extends 300 to 400 n.m. away from the station (over an area 50 to 300 n.m. wide), may reach 1° on the bisector and 5° on a line 60° away from the bisector towards the baseline. This error may be plotted as a curve, in terms of the D.R. The table below briefly classifies systematic errors :

CONSOL ACCURACY IN ZONE B

Distance from Bisector	Systematic error	In 50 % of readings: Mean random error	In 50 % of readings: Total error	In 90 % of readings: Mean random error	In 90 % of readings: Total error
0°	0° +	0.2°	= 0.2°	0.8°	= 0.8°
40°	1° +	0.5°	= 1.5°	1.7°	= 2.7°
60°	3° +	0.8°	= 3.8°	2°	= 5°

Note. These figures are valid for a path over water. German research in connection with the Warsaw Consol system supplies identical errors during daylight (direct waves) and higher figures for night error beyond 600 n.m. The table below compares both types of distance covered:

ERROR IN TERMS OF DISTANCE COVERED			
Distance		Over Sea	Over Land
300 n.m.	At 25° from bisector	1°	4°
	At 60° from bisector	4°	Over 6°
1,000 n.m.	At 25° from bisector	0.5°	3.5°
	At 60° from bisector	0.7°	4.5°

In Loran, the presence of reflected waves has no effect on accuracy, since the operator may *visually* select the signals and if need be apply a correction supplied by a curve during the deliberate matching of a direct wave and a reflected wave. The distorsions of the reflected waves on the Loran display, which are due to variations in the ionized layers, are no great handicap, as they occur periodically at a rapid rate. A brief amount of training enables assessment of the instant when two reflected signals may be matched. Assuming for practical purposes a maximum reading error of 5 μs, the following average positional accuracy is obtained from a triplet (two Masters and one Slave) :

LORAN		
Distance	Direct Wave	Reflected Wave
50 n.m.	0.2 n.m.	
270 n.m.		2 n.m.
500 n.m.	1 n.m.	
1,500 n.m.		8 n.m.

Accuracy is generally higher than 1% of the distance, taking the following figures as an average:

Distance (D)	In 50 % of readings	In 90 % of readings
500 n.m.	0.2 % of D	0.6 % of D
1,200 n.m.	0.3 % of D	0.9 % of D

It should be noted that 1% of the distance (which is the assumed Loran error) is equivalent to 15 n.m. at 1,500 n.m., or to an angular error in the neighbourhood of 0.5°. When conditions prevailing at the 50 % level are taken, involving an accuracy of 0.3%, the error becomes 4.5 n.m., which is equivalent to an angular error of 0.2° (1/5th degree).

As regards Consol, assuming in practice a loss of four signals during the count, it is wise to consider the applicable error in terms of D.R., as in the following table:

CONSOL				
	BY DAY		BY NIGHT	
Distance from bisector	1°	60°	1°	60°
Range 25 to 300 n.m.	0.2° to 0.5°	0.4° to 1°	0.2° to 0.5°	1.5°
300 to 500 n.m.	0.2° to 0.5°	0.4° to 1°	0.5° to 0.8°	1.5° to 5°
500 to 1,500 n.m.	0.2° to 0.5°	0.4° to 1°	0.2° to 0.5°	1.5°

The above angular errors supply the following errors in range (or lateral discrepancies) when plotting the fix on the chart:

CONSOL				
	BY DAY		BY NIGHT	
Azimuth	1°	60°	1°	60°
Range 300 n.m.	1.5 to 3 n.m.	2.5 to 5.5 n.m.	1.5 to 3 n.m.	8 n.m.
500 n.m.	2 to 4 n.m.	3.5 to 8.5 n.m.	3 to 6.5 n.m.	13 to 44 n.m.
1,500 n.m.	6 to 12 n.m.	10.5 to 25 n.m.	6 to 12 n.m.	40 n.m.

COMPARED ACCURACIES		
	CONSOL	LORAN
Mean reading error	Four signals	5 μs
Error of plot at 1,500 n.m.	6 to 40 n.m.	4.5 to 15 n.m. (8 n.m. at 95 % level)
Angle error at 1,500 n.m.	0.2° to 1°	0.2° to 0.5°
Error of plot at 500 n.m.	3 to 44 n.m.	1.5 to 5 n.m.

COMPARISON WITH RADIO DIRECTION FINDING

It would be useful, in ending this discussion on comparative accuracy, to know precisely the effect of the coast and weather areas where such factors as temperature and humidity play a part, which act as prisms in the Consol frequency band. Such factors are not yet known, but it appears that most of the errors found in radio direction finding (in which the angle subtended by the base line is also small) are likewise true for Consol (Consol, after all, is but a special frame-aerial combination, in which the end antennas operate as an Adcock frame). Such processes are almost non-existent, in Loran, where the presence of a coastal band affects signal level (absorption); but on the assumption that refraction is equivalent to that encountered in direction finding, the resulting increase in path length would appear to be negligible.

NOISE LEVEL AND INTERFERENCE

In radioelectricity the sensitivity of a receiver (or its gain) is basically of slight importance. The determinant factor is its signal to thermal noise ratio. Thermal noise is primarily produced by the first high frequency stages. The limit of sensitivity in a receiver may be defined by the thermal noise occurring in the purely ohmic part of the input impedance. It is readily apparent that a receiver enabling either Loran or Consol signals to be obtained requires careful design. The question does not arise in the case of Loran, which uses a specially adapted receiver, but the remark currently heard that « Consol may be received with *any type of receiver* » represents such an elementary view that it need not be enlarged upon. The only effective way of increasing the signal to noise ratio is to decrease the threshold of sensitivity in the receiver, i.e. to reduce the band pass dF, since K (Botzmann's constant) cannot be dealt with. This is impossible in Loran, as the receiver has a fixed 70 kc/s 6 db band pass, so designed as to produce no excessive distortion in the aspect of the impulses (elimination of component frequencies, Fourier series). On the average, receivers presently available (of the communication type) have a selectivity of 3 kc/s at 6 db. Those with a quartz filter are reduced to 200 and 800 c/s at 20 db. But the filter weakens the signals by about 6 db. When used for Consol signal detection in an area of high interference a maximum increase of 10 db is obtained in signal-to-noise ratio. Such a result, by acting upon the transmitter alone, could only be obtained by multiplying the output power by 10 (from 2 kW to 20 kW). This likewise shows the need for a well-designed airborne receiver.

TYPES OF INTERFERENCE

The presence of a band filter enables the reduction of interference arising from transmission on neighbouring frequencies. This type of interference, during the detection of Consol signals in the Atlantic, is generally caused by ship transmitters radiating a large number of harmonics (absence of separator, etc). This results in signal interference even with a band reduced to 200 kc/s at 20 db.

The question of atmospheric interference takes a different form, and two types should be considered during Consol signal detection :

(a) Interference occurring over a period of more than 5 or 6 *consecutive* seconds every half-minute. In this case, no readings are possible, as the number of signals « skipped » is too large in ratio to the dot and dash sectors (except in the very special case of a large number of signals of the same type, say fifty dots or dashes, where the rate of signals lost during interference may be evaluated);

(b) Interference with an average duration of 2 or 3 seconds or fraction of a second, spaced 5 or 6 seconds apart per half-minute. In this case, a mental count of the signals may be made during interference by evaluating the rate. Use of a chronometer for reading purposes does not appreciably improve aural detection, as the interference problem is transferred to the start of the cycle and passage of the equisignal. Moreover, when the length of the cycle is less than one minute, the minute requires an additional mental operation.

In Loran, interference appears as :

(a) « Grass » on the sweep;

(b) « Ghost » signals during the interference of other Loran stations;

(c) Saturation of receiver when radio interference is sufficiently powerful : the Loran signals appearing on the screen then decrease in amplitude and may even disappear altogether;

(d) An image of the modulation supplied by radiotelephonic transmission, which may also block the receiver;

(e) Stable signals or « pips » during radar interference.

Each type of interference thus supplies a different image, depending upon its nature. (Another basic type moreover exists produced by pips with a carrier frequency and synchronization out of tune with the receiver). Such interference, under the most unfavourable conditions, results in a distortion of the impulses received. In any case, readings remain possible when the amplitude of the interfering signals is ten times greater than that of signal reception (*negative signal to noise ratio* : 20 db). This does not apply in the case of Consol, where a signal-to-noise ratio of 1 limits its use in practice. As in principle interference is intermittent, the superior quality of visual observation is here fully apparent, since readings are thus rendered possible during an interference interval. Experience shows that in the majority of cases Loran readings were possible even in such regions as the Azores and Bermuda, where the level of interference is high. Interruption periods in these areas in no case lasted over one half-hour.

REDUCTION OF RANGE DUE TO INTERFERENCE

This can only be estimated with great difficulty, as reports covering practical tests during flight are limited and thus preclude statistical analysis. According to a mathematical analysis made by the Marconi Company prior to the siting of Consol stations in the Sahara (a subtropical area), an attenuation of range occurs depending on the time of day (atmospheric interference higher at night than during daylight). The following table summarizes such ranges (the power radiated by the transmitter is 1 kW., thus requiring an output power close to 4 kW.; ranges shown were obtained in 90% of cases; band pass: 400 cycles; distances in statute miles):

CONSOL			
PLACE	TIMES		RANGE DIFFERENCE
	0400 UT	1600 UT	
Dakar	900 SM	350 SM	550 SM
Aoulef	1,200 SM	310 SM	890 SM
Lomé	900 SM	350 SM	550 SM

Although submitted in different form, reports drawn up by the Telecommunication Research Laboratory, Pretoria, S.A., show appreciably identical results, derived from practical tests. The published result dated March 1951 merely states that: « By using a radiated power of 1 kW (output power 4 kW) a 200 statute mile range may be obtained in 90% of cases with an accuracy of ± 1°". In such cases, severe weather conditions considerably reduce the range and accuracy of Consol, which no longer meets long-range navigational requirements. The detection of Consol signals under heavy interference conditions is reduced to the perception of slight variations in strength. This question was investigated by Fletcher, who plotted curves showing the minimum increase in strength perceptible to the ear, in terms of frequency and strength of sound. Such curves indicate that the use of a low-frequency output power at the receivers approaching 3000 c/s is advisable for optimum aural sensitivity. This frequency varies with the individual, and a heterodyne with a variable beat frequency is recommended. This constitutes an additional factor to those described previously in favour of a high-grade receiver for Consol reception. A further argument in favour of a variable-frequency heterodyne is the possible selection of the incident signal as against the interfering signal, which is never of identical frequency.

INFLUENCE OF CONSOL KEYING RATE

Owing to the various types of interference met with, a rapid rather than a slow rate of keying appears preferable. This rate is limited, owing to the operator factor, to about 120 signals per minute. Experienced operators may read from 360 to 400 signals per minute (which is the telegraphic press rate), so that the 120-signal rate may easily be read. The fact that Consol is used by fishermen is no valid argument for limiting the rate to 60 signals per minute. Mariners and fishermen can easily adapt themselves to the 120-signal rate, in spite of the attempted insinuations of certain articles on the subject. The resulting added accuracy is sufficient justification for the sustained attention required during readings. An increased accuracy will doubtless be obtained when an automatic indicator is designed, provided the keying rate is increased to 800 or 1,000 signals per minute. Such a cycle would be unintelligible to the human ear, but would be repeated a greater number of times each minute. The problem will closely resemble those encountered in present-day radio-teletype communication, requiring special averaging equipment and eliminating human interpretation altogether. Since such conditions do not now exist, they need not be considered for Loran comparison purposes.

SIMILARITIES OF OPERATIONAL USE

The currently-heard opinion that « anyone » may obtain a Consol fix « anywhere » with « any receiver » reflects a total lack of understanding of the practical use of Consol and of the basic technical principles from which it is derived. If an analysis is made of the various operations required for obtaining a Loran or Consol position line, it will be seen that an equivalent number of steps is required and that Consol is more complex, in spite of the opinion generally held. The various operations are tabulated below:

LORAN	CONSOL
Display of chain number by three knobs (Ex.: 1H4).	Manual tuning of communications receiver (pure continuous wave, range and frequency). Note: Direct display of station's name with a special receiver which is not yet available on the market.
Synchronization of « pips » and position of markers.	Operation of band pass filter heterodyne beat.
Matching of pips.	Signal counting.
Interpretation of impulse distortions (in case of interference).	Interpretation of equisignal period or signal counting with chronometer (in case of interference).
Reading on electronic scale or direct reading on latest model of Sperry receiver.	Deduction from 60 and proportional distribution of error.
Reading or direct plotting on chart.	Deduction from 60 and proportional distribution of error.
Duration: less than three minutes for three position lines.	Duration: at least six minutes for three position lines.
Special receiver, easy to operate after one hour of practice.	Communications receiver, delicate to operate and requiring a knowledge of radio.

The obtaining of a Consol reading requires skill in operating the receiver so that the signal « stands out », by actuating the high-frequency tuning control, band pass, heterodyne and gain controls. Radio operators are accustomed to handling this type of problem, but an average technical knowledge is required. The use of Loran may initially appear much more complex. Constant observation during a period of one hour enables the advantages to be realized of a receiver specially designed for the measurement required. The number of control knobs is quickly forgotten, since each corresponds to an « image » or the correction of an « image » on the display. A ten-hour test during flight is enough to supply an understanding of the principle of impulse distortion. The use of communications receiver requires a great deal more time as the operator must *understand* the operations he carries out, while in Loran he *sees* them. In short, Consol makes demands on aural memory and Loran on visual memory. The latter can be developed much more readily.

INFLUENCE OF DEAD RECKONING

The operator of a Loran receiver need only have a very approximate knowledge of his D.R., as even in the vicinity of the stations the accuracy of readings is nowise affected. An accurate knowledge of the D.R. in Consol, on the other hand, is essential in order to determine:

(a) the reading sector;

(b) the unusable sector;

(c) the accuracy to be attributed to the measurement.

In practice, it does not appear reasonable to consider navigating exclusively by Consol, as a basic error in D.R. may affect the navigation occurring thereafter without unduly attracting the user's attention. This has unfortunately happened often enough to obviate the need for further comment.

SUMMARY

Under the most unfavourable conditions, the plot of a Consol position line may be affected by an error of 44 n.m., while *the maximum theoretical error of Loran is 15 n.m.*

The speed of interpretation of Loran is higher than in Consol.

The signal-to-noise ratio (for a given noise) will be *higher in Loran* owing to differences in radiated power (75 kW in Loran as against 1/2 kW in a standard Consol station).

The locus of equivalent accuracy surrounding a Consol station has reached its technical limits as regards the stations presently used; the locus may be increased in the case of a Loran chain by increasing the length of the base line.

Reflected waves largely affect the accuracy and easy reading of Consol. *They have no effect whatsoever on Loran.*

The airborne receiver must have the same high technical qualities in Consol as in Loran, in order to obtain maximum results (in the absence of a special receiver the power of Consol transmitters should be increased tenfold).

Atmospheric interference largely affects the reading accuracy and range of Consol signals (range reduced by 75 %). It has in practice but little effect on Loran signals (range reduced by 10 %), in which each type of interference produces an applicable image.

The training of user personnel is easier and more rapid in the case of Loran, contrary to widely prevalent opinion, because Loran makes demands on visual memory. The user of Consol must « understand » his operations, while the Loran user « sees » them.

Dead reckoning must be maintained at a much higher level of accuracy when using Consol (owing to the risk of ambiguity which is nonexistent in the case of Loran).

Overland paths do not exist in the case of Loran, but the error involved in Consol beyond 300 n.m. (over 6°) limits its effective range.

CONCLUSION

The problem of « interpreting » results obtained applies to all types of measurements and is beyond the mere scope of Loran and Consol. Interpretation of a measurement requires:

(a) Basic technical knowledge;

(b) Practical experience;

(c) An order of magnitude of results.

Whatever the measuring instrument used, it is *essential* that the user be sufficiently competent to interpret the information received, even after the addition of more or less automatic equipment. The use of a D.R. computer does not necessarily mean the absence of nautical knowledge. The same applies in the case of radionavigational equipment. The instance of the automatic radio compass was sufficiently costly for users to learn the necessity of keeping robots under control. This has the result of eliminating « Mr Anybody » in the conduct of air navigation.

To conclude, we believe that Loran, which has greater flexibility of performance, bears no technical or operational comparison with Consol in its present state. The financial aspect may invalidate such a conclusion. However, it seems logical, pending the development of future systems which show great promise but have not yet gone beyond the laboratory stage, to strive for maximum security when setting up new radionavigational aids.

REMARKS

When discussing the subject of Loran and Consol, it will be advisable to examine with care the types of stations and airborne equipment used. The reference sources used by us dealt with Standard Loran (peak output power : 100 kW) and Standard Consol (output power : 2 kW).

Several sources (among them the report of the Fourth Meeting of COMITEM 13-2, dated May 1950) supply information on the range and accuracy of experimental Consol using three 10-kW transmitters each powering an aerial at 70 % efficiency. Total radiated power is then 21 kW intead of the 1/2 kW power of Standard Consol.

The « Sonne » transmitter tried out by CAA at Allaire (U.S.A.) also radiated a power of 8 kW per aerial (i.e. a total of 24 kW as against 1/2 kW in Standard Consol). These figures must be kept in mind when analysing results obtained by commercial crews during test flights in 1950.

Finally, in such trials, the frequency used was lowered to 193 kc/s (as contrasted with present frequencies of approximately 250 kc/s) and a special receiver was used with a band pass of 20 c/s, while present receivers, equipped with a quartz filter, have a band pass as high as 200 c/s.