IALA

IALA GUIDELINE

1010

RACON RANGE PERFORMANCE

Edition 2.0

June 2005

10, rue des Gaudines - 78100 Saint Germain en Laye, France
Tél. +33 (0)1 34 51 70 01- Fax +33 (0)1 34 51 82 05 - contact@iala-aism.org
www.iala-aism.org
International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime

DOCUMENT REVISION

Revisions to this IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision
June 2005	• Section 1 – Introduction • Section 2.1 – Radar Operating Band • Section 3.4 – RACON Tracking Accuracy • Section 3.5 – Radar Performance Standards • Formatting - General	Reflect changes in ITU and IMO documentation regarding radar performance and spectrum use.

CONTENTS

List of Tables

CONTENTS

List of Figures

1 INTRODUCTION

The method recommended by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) for publishing the nominal range of a radar beacon (RACON) installation, is to quote the distance at which the RACON is likely to be first detected, with assumed values for heights and powers of radars as fitted typically to a range of vessels.

Four vessel type / radar size combinations, each capable of being installed at two different heights, are considered:

IMO MSC79 has approved radar performance Resolution 192(79) which has removed the requirement for 3 GHz (S-Band) radars to trigger RACONs. Because of this, 3 GHz operation is not discussed explicitly. However, 3 GHz radar signal behaviour is similar to 9 GHz and many of the same effects can be observed

Table 1 Radar types

Vessel type	Band[1]	Power	Antenna		Height Above Sea Level (ASL), metres	
			Gain dBi	Size metres	(A)	(B)
(1) Pleasure/small	9 GHz	4 kW	25	0.9	3	6
(2) Small commercial	9 GHz	10 kW	29	1.2	5	10
(3) Large commercial	9 GHz	25 kW	31	2.4	15	35

Apart from the effective power output of the radar, the most significant parameters affecting the nominal range are the heights of the RACON and the radar scanner above sea level.[2] In all the combinations of Table 1 the strength of the radar signal received at the RACON is more critical than the return path and determines whether the RACON will transmit a response.

The RACON nominal ranges given in this note should be taken only as an approximate guide. In addition to the effective output power of the radar and the heights of the radar and RACON, the following factors have a major influence on whether the RACON can be seen on the radar display.

2 FACTORS UNDER THE CONTROL OF THE RADAR OPERATOR

2.1 RADAR OPERATING BAND

Some RACONs are only single-band. The radar display being observed must be connected to a radar head operating on the correct band for such a RACON. If a shipborne radar system has interswitching capability, it may not be immediately obvious which transmitter / receiver unit is connected to a particular display. In addition, the operator should be aware that some new 3 GHz radars might not trigger or detect RACONs (section 3.5 refers).

2.2 DISPLAY SETTINGS

The radar must be switched to a display range scale appropriate for the distance of the RACON from the vessel. It must be correctly adjusted, particularly the anti-clutter settings

1 The 9 GHz band was previously known as X-band. It is also known as the 3 cm band. The 3 GHz band was previously known as S-band. It is also known as the 10 cm band.

2 Throughout this note, RACON and radar heights may be interchanged. For example, the performance of a RACON at 6 m ASL on a radar at 35 m ASL would be identical to that of the same RACON at 35 m ASL on the same type of radar at 6 m ASL.

2.3 AWARENESS OF CERTAIN OPERATING CHARACTERISTICS OF RACONS

The observer must be aware that RACONs are programmed and are active for only (typically) 15 seconds in each minute.

3 FACTORS NOT UNDER THE CONTROL OF THE RADAR OPERATOR

3.1 THE PROPAGATION CHARACTERISTICS OF THE INTERVENING ATMOSPHERE

The propagation characteristics of the atmosphere between radar and RACON at the time have a major influence on the performance of a RACON, particularly at distances greater than about 10 NM. The usual effect of the vertical profile of the refractive index is to cause the radar frequency energy to follow a path that is curved very slightly downwards. This curvature is taken into account in calculations of range performance by using a hypothetical value for the radius of the earth of 'k' times its true value.

The normal[3] value of factor 'k' is taken to be (4/3) = 1.33. At night and in bad weather conditions the assumed value of 'k' should often be considerably lower than this. Conversely, in good daytime conditions a higher value should be taken. In temperate climate areas 'k' is typically between 1.0 and 2.0. However, it can be as low as 0.8 which may reduce RACON range performance by more than 50%. Alternatively, it may be as high as 10 possibly increasing RACON range performance by a similar factor. These conditions are often referred to as 'anomalous propagation' – colloquially as 'anaprop'[4]. Unfortunately, there is no practical way to find an appropriate value for 'k' other than retrospectively, either by calculation from detailed atmospheric profile measurements or by empirical matching to observed radar performance.

Precipitation, either at the RACON site where it may produce obscuring clutter at medium to short range, or in a significant portion of the path between radar and RACON where it may introduce significant signal attenuation on a 9 GHz radar, will reduce the effective detection range of a RACON. The presence on the radar display of sea, rain or land clutter in the vicinity of the RACON will reduce the ability to detect its response due to obscuration.

All these propagation characteristics also affect detection of normal radar targets such as ships and coastlines.

3.2 FADING DUE TO MULTI-PATH INTERFERENCE

The second external factor, which is seldom experienced in detection of normal radar targets[5], is fading due to multi-path interference. Figure 1 shows a typical example of the variation of the received signal with distance. The smooth curve represents the signal that would be received in the absence of any sea-surface reflection - the 'free-space' condition.

In practice the signal received is the vector sum of the direct path signal and its reflection in the sea surface. For given heights of radar and RACON, the difference in length between the direct and indirect paths varies with the distance between radar and RACON, and hence the phase of the two signals also varies. When they arrive in-phase [6] the vector addition gives up to 6 dB uplift. When they arrive in opposite phase, there is (theoretically) almost total cancellation, a null. This condition is most marked when the sea is calm and is commonly called 'multi-path fading'[7]. This modulation of the free-space propagation curve is shown in Figure 1.

The RACON will be triggered only if the combined signal received (i.e. the resultant vector sum of the direct and reflected rays) is above its receiver threshold. At radar-RACON separations where the combined signal is below the threshold, the RACON will not be triggered. By convention, the active zones are called 'lobes', from the shape

---

3 The word 'normal' is used here to follow the practice of most textbooks on the subject. 'World-wide annual average' would be a better term because the value which should be used varies significantly with location and from hour to hour.

4 Ducting, an extreme form of anaprop in which radar rays become trapped within a height band of a few tens of metres either at, or a few metres above, the sea surface, may be encountered occasionally. This results in severe radar performance loss.

5 Because such targets consist of many uncorrelated individual reflectors whereas a RACON antenna is effectively a single point.

6 Note that there is a 180°phase shift at the point of reflection.

7 The geometry of the ray diagram depends on the value of 'k', hence so do the positions of the lobes and nulls.

of vertical profile plots as shown in Figure 2 to Figure 7. Between the lobes are 'fade zones' or 'nulls', in which the RACON is not triggered. The extent of a fade zone is typically in the order of 3 to 10% of its range the first (longest range) being the widest and deepest. A fade will seldom persist on the radar of a moving vessel because the distance between radar and RACON will usually be changing but could be of significance when planning the siting of a RACON especially in the vicinity of a Traffic Separation Scheme.

3.3 BLIND ARCS

A final factor, which applies equally to normal radar working, is the possible influence of the vessel superstructure and the siting of the radar antenna. On many vessels the strength of signal received from RACONs, and echoes from other targets, may vary according to the relative bearing of the RACON or target, - 'blind or semi-blind arcs'. Likewise, the RACON must be installed with a clear view of the sea area of interest.

3.4 RACON TRACKING ACCURACY

Individual radars transmit at various frequencies within the band. For a RACON to be detected by a radar, the RACON needs to respond at that radar's frequency. The process of measuring the radar frequency and adjusting the RACON transmission frequency to match is not perfect, and some error in frequency tracking can be expected. Radar receivers have narrow band pass filters to exclude signals that are not wanted. Thus, RACON tracking error appears to degrade the RACON's signal strength.

The effect of tracking error can be quantified. ANNEX B, Discussion on Tracking Accuracy and Effect on RACON Range, refers.

3.5 RADAR PERFORMANCE STANDARDS

IMO performance standards do not require 3 GHz radars to trigger or detect RACONs.

Because of changing ITU requirements, new generation radars must have reduced emissions and might not trigger or detect existing RACONs. It is unlikely that regulations will change again before 2012.

4 ESTIMATION OF RACON RANGES

4.1 CAUTIONARY NOTE

Computer programs can be written which calculate and plot the relationships between received signal strength and distance from radar to RACON for any set of equipment parameters and assumed propagation characteristics. Such a set of programs (see section 7) has been used to produce the tables and graphs that follow. However, because of all the variables involved and the unpredictability of some of them, notably 'k', it would not be of great value, and indeed could be misleading, to attempt to define with any precision the detection ranges and the positions of the fade zones of RACONs.

4.2 SAMPLE RESULT GRAPHS

Sample result graphs are provided in Figure 1 to Figure 7.

4.2.1 FIGURE 1

This shows the variation with distance of the radar signal at the RACON receiver for one set of radar parameters (3 A in Table 1), RACON height of 60 m and an assumed value 'k' = 1.33. The variation as it would be in free-space is shown as well as the practical case with multipath interference. The standard triggering threshold for a 9 GHz RACON (-40 dBm) is shown. The effect of homogenous rainfall over the whole path length, which introduces attenuation increasing linearly with distance, can be simulated by drawing a threshold line that rises at the appropriate rate. An example line is shown at 0.1 dB/NM, which corresponds very approximately to moderate rain of 4 mm/hour on a 9 GHz system.

Indications of the variation of nominal range and the position and shape of the first (i.e. longest range) three lobes for a variety of radar/RACON combinations, with RACON height as the independent variable, are shown in graphical form in Figure 2 to Figure 9. 'Outside' the solid line lobe-shaped areas are the height and distance combinations where the RACON does not respond to the radar, 'Inside' the lobes are where the RACON responds to the radar. Also shown in each figure are the dotted line lobe-shaped areas that illustrate the effects of a combined reduction of 6 dB in the effective radar power output and RACON sensitivity due to service deterioration.

4.2.2 Figure 2

Typical pleasure or similar small craft with a 4 kW 9 GHz-band radar installed 3 m above sea level (1 A in Table 1).

4.2.3 Figure 3

As Figure 2, but with the radar installed 6 metres above sea level (1 B in Table 1).

4.2.4 Figure 4

Typical small commercial ship or fishing vessel with a 10 kW 9 GHz-band radar installed 5 metres above sea level (2 A in Table 1).

4.2.5 Figure 5

As Figure 4, but with the radar installed 10 metres above sea level (2 B in Table 1).

4.2.6 Figure 6

Typical large commercial ship with a 25 kW 9 GHz-band radar installed 15 metres above sea level (3 A in Table 1).

4.2.7 Figure 7

As Figure 6, but with the radar installed 35 metres above sea level (3 B in Table 1).

5 EXAMPLES

To aid in using the RACON Range Diagrams (Figure 2 to Figure 7), two examples are given. The first example presents the general technique for using the diagrams. This is done by showing how to analyse the performance of a radar for a particular RACON installation. The second example builds on the general technique and outlines a procedure for evaluating a potential RACON site for the expected vessel (and thus, radar) traffic.

5.1 RADAR-RACON ANALYSIS

The expected maximum range of the radar-RACON combination and the location of any nulls that might be encountered can be read from the diagrams. The general procedure for determining range and null locations is as follows:

1 Using the appropriate diagram for the vessel type, draw a line across the diagram at the RACON height.

2 Follow the line just drawn from the right hand side of the diagram until the first lobe is reached; this point is the maximum RACON range.

3 Continue following the line to the left until the first lobe is cleared; this point is the distance to the first null

4 Continue following the line to the left until the next lobe is reached; the difference in distance between this point and the last is the width of the first null area.

5 Steps 3 and 4 can be followed again to determine the second null area.

There are other nulls further to the left (closer distances to the RACON), but they are very narrow. In actual practice, these nulls are effectively non-existent for a moving vessel.

Figure 8 is an example using a RACON height of 60 m and a vessel type of 1A. In this example, the maximum range is about 12.0 NM, the first null is from about 6.1 NM to about 5.0 NM and the second null is from about 3.0 to 2.8 NM.

5.2 RACON SITE EVALUATION

There are two RACON siting issues considered. The first issue is to determine that the maximum ranges for the expected radar types are adequate for the location. The second issue is to determine that none of the null areas fall over an inconvenient point. The following steps are used:

1. Select a candidate RACON height.
2. For each vessel type, determine, from the diagrams, the maximum range, and the locations and width of the first two null areas; enter these values into a table.
3. For each vessel-type table entry, determine if the maximum range is adequate for the intended service; if any table entry is inadequate, then a new height must be chosen and this procedure redone.
4. For each vessel-type table entry, determine if any of the null areas fall over an inconvenient point; if any null point is inconvenient, then a new height must be chosen and this procedure redone.

Table 2 is an example of this technique for a potential RACON height of 60 m for all eight radar types.

Table 2 Ranges and Nulls

Vessel Type	Maximum Range	First Null		Second Null	
		Maximum	Minimum	Maximum	Minimum
1 A	12.0	6.1	5.0	3.0	2.6
1 B	14.0	10.8	8.4	5.9	5.2
2 A	16.5	8.5	7.5	4.9	4.5
2 B	19.0	12.7	11.7	7.5	7.0
3 A	22.5	15.0	14.5	11.0	10.8
3 B	27.5	21.5	20.5	17.5	17.0

In any case, the cautions of section 4.1 must be kept in mind.

6 CONCLUSIONS

The complexity inherent in predicting propagation of radio waves at the frequencies used in marine radar is emphasised in sections 3.1, 3.2 and4.1 above. Noting this, the expected detection ranges of RACONs at various heights above sea level, derived from Figure 2 to Figure 7, are shown in Figure 9 and may be sufficient guidance in many cases.

The providing authority should be aware that, for the reasons demonstrated in sections 3 and 4, fade zones occur at distances within the nominal detection range. In those circumstances where the reception of a RACON is particularly important and where the distance from the vessel to the RACON remains nearly constant, for example in a Traffic Separation Scheme, the installation of two RACON at different heights, to provide space diversity, should be considered.

In cases where a more detailed analysis of the structure of the lobe and fade zones is required, computer programs such as those used to compile the data and graphs for this note should be used.

7 DEFINITIONS

The definition of terms used in this Guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary.Acronyms, via the approved server.

8 ACRONYMS

ASL	Above Sea Level
dB	decibel
dBi	decibel (referenced to isotropic radiator)
dBm	decibel (referenced to milliwatts)
FOM	Figure of merit
GHz	GigaHertz
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities - AISM
IMO	International Maritime Organization
ITU	International Telecommunication Union
k	hypothetical factor for use with the radius of the earth
kW	kilowatt
m	metre
MHz	Megahertz
mm	millimetre
MSC	Maritime Safety Committee (IMO)
mW	milliwatt
NM	nautical mile
RACON	RADar beaCON (Radar transponder beacon)

9 REFERENCES

[1] Private communication and computer programs, G F M Walker (Australian Maritime Safety Authority)

[2] The Radar Handbook, edited by Merrill Skolnik, Published by McGraw-Hill, 1970 & 1990 editions.

[3] Estimated Range of Radar Beacons, P Blaise, IALA 1985 Conference, Paper 6.3.1.

ANNEX A TYPICAL RACON PERFORMANCE

A 1. LARGE COMMERCIAL (RADAR ANTENNA HEIGHT 15 m)

Radar & Racon Parameters:

Frequency:	9.40	GHz
Wavelength:	3.19	cm
Polarisation (V or H):	H	
Radar Transmitter Power:	25	kW
Radar Antenna Gain:	31	dBi
Radar Receiver Sensitivity:	-95.5	dBm
Racon Transmitter Power:	1	watt
Racon Antenna Gain:	4.5	dBi
Racon Receiver Sensitivity:	-40	dBm

Geometry & Environment:

Radar Height:	15.0	m
Racon Height:	50.0	m
Refraction Constant 'k':	1.33	
Wave Height:	0	m (crest to trough)
Maximum Geometric Range:	24.36	nautical miles
Critical Path:	Radar to Racon	

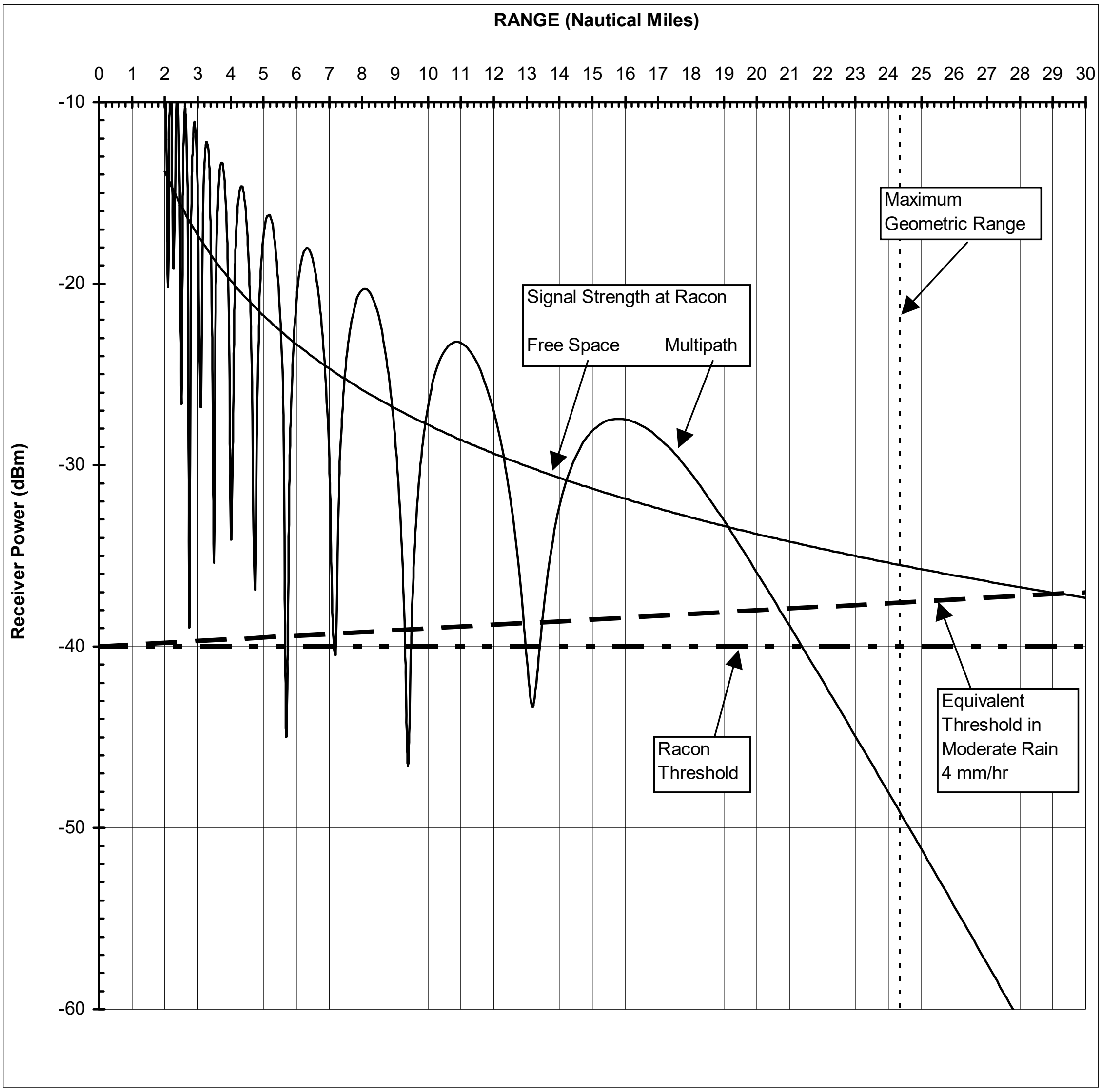


Figure 1 Typical RACON performance (Table 1, 3A)

A 2. SMALL CRAFT (RADAR ANTENNA HEIGHT 3 m)

Vessel Type: **Small Craft (Radar Antenna Height 3 metres)**

Radar Parameters:

Power	4	kW
Antenna Gain	25	dBi
Receiver Sensitivity	-95.5	dBm

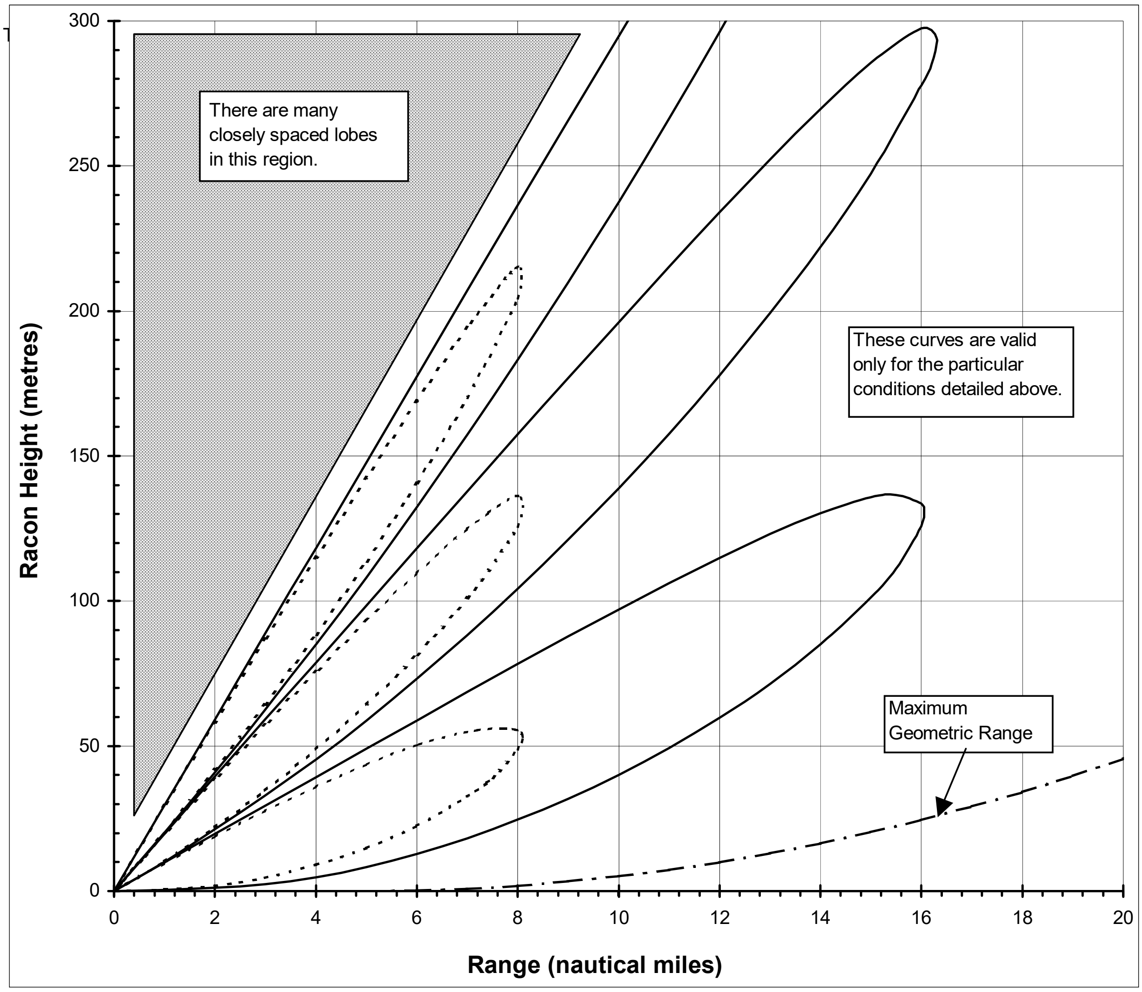
Racon Parameters:

Power	1	watt
Antenna Gain	4.5	dBi
Receiver Sensitivity	-40	dBm

Critical Path: Radar to Racon

Environment:

Refraction Constant (k)	1.33	
Wave Height	0	metres (crest to trough)



The graph shows the maximum geometric range and the first three lobes caused by multipath effects due to reflection at the sea surface, plotted as a function of racon height above sea level. Interference nulls are also present above the third lobe, but are generally only of small range duration. To use the graph, enter with racon height (assumed to be the same as the associated light if not specifically quoted) and read off the maximum detection range and the ranges at which signal loss due to the multipath effects will be experienced. The curves inside the main lobes are calculated for a 6 dB loss of performance and indicate the range reduction if such losses are present.

Figure 2 RACON range diagram – 9.4 GHz (Table 1, 1A)

A 3. SMALL CRAFT (RADAR ANTENNA HEIGHT 6 m)

Vessel Type: **Small Craft (Radar Antenna Height 6 metres)**

Radar Parameters:

Power	4	kW
Antenna Gain	25	dBi
Receiver Sensitivity	-95.5	dBm

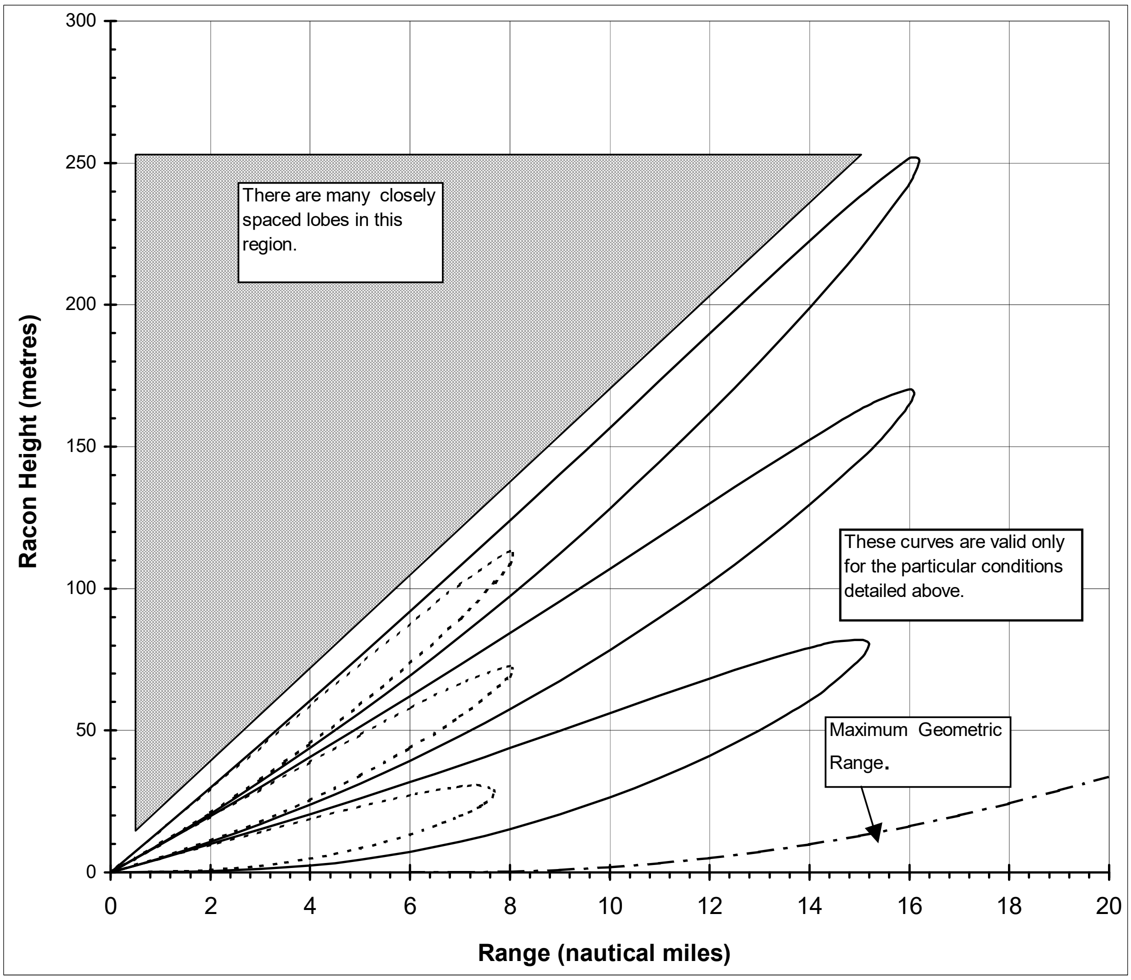
Racon Parameters:

Power	1	watt
Antenna Gain	4.5	dBi
Receiver Sensitivity	-40	dBm

Critical Path: Radar to Racon

Environment:

Refraction Constant (k)	1.33	
Wave Height	0	metres (crest to trough)



The graph shows the maximum geometric range and the first three lobes caused by multipath effects due to reflection at the sea surface, plotted as a function of racon height above sea level. Interference nulls are also present above the third lobe, but are generally only of small range duration. To use the graph, enter with racon height (assumed to be the same as the associated light if not specifically quoted) and read off the maximum detection range and the ranges at which signal loss due to the multipath effects will be experienced. The curves inside the main lobes are calculated for a 6 dB loss of performance and indicate the range reduction if such losses are present.

Figure 3 RACON range diagram – 9.4 GHz (Table 1, 1B)

A 4. SMALL COMMERCIAL (RADAR ANTENNA HEIGHT 5 m)

Vessel Type: **Small Commercial (Radar Antenna Height 5 metres)**

Radar Parameters:

Power	10	kW
Antenna Gain	29	dBi
Receiver Sensitivity	-95.5	dBm

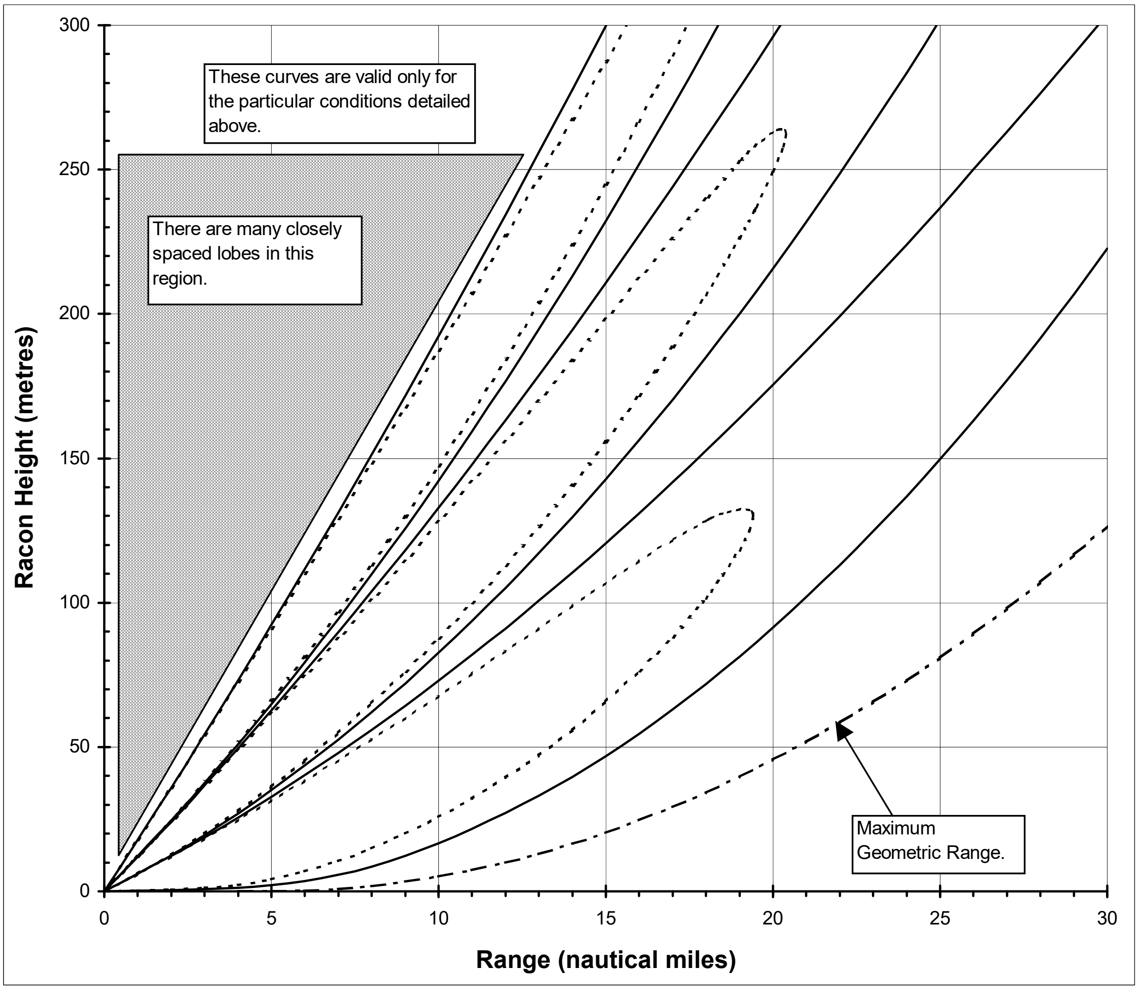
Racon Parameters:

Power	1	watt
Antenna Gain	4.5	dBi
Receiver Sensitivity	-40	dBm

Critical Path: Radar to Racon

Environment:

Refraction Constant (k)	1.33	
Wave Height	0	metres (crest to trough)



The graph shows the maximum geometric range and the first three lobes caused by multipath effects due to reflection at the sea surface, plotted as a function of racon height above sea level. Interference nulls are also present above the third lobe, but are generally only of small range duration. To use the graph, enter with racon height (assumed to be the same as the associated light if not specifically quoted) and read off the maximum detection range and the ranges at which signal loss due to the multipath effects will be experienced. The curves inside the main lobes are calculated for a 6 dB loss of performance and indicate the range reduction if such losses are present.

Figure 4 RACON range diagram – 9.4 GHz (Table 1, 2A)

A 5. SMALL COMMERCIAL (RADAR ANTENNA HEIGHT 10 m)

Vessel Type: **Small Commercial (Radar Antenna Height 10 metres)**

Radar Parameters:

Power	10	kW
Antenna Gain	29	dBi
Receiver Sensitivity	-95.5	dBm

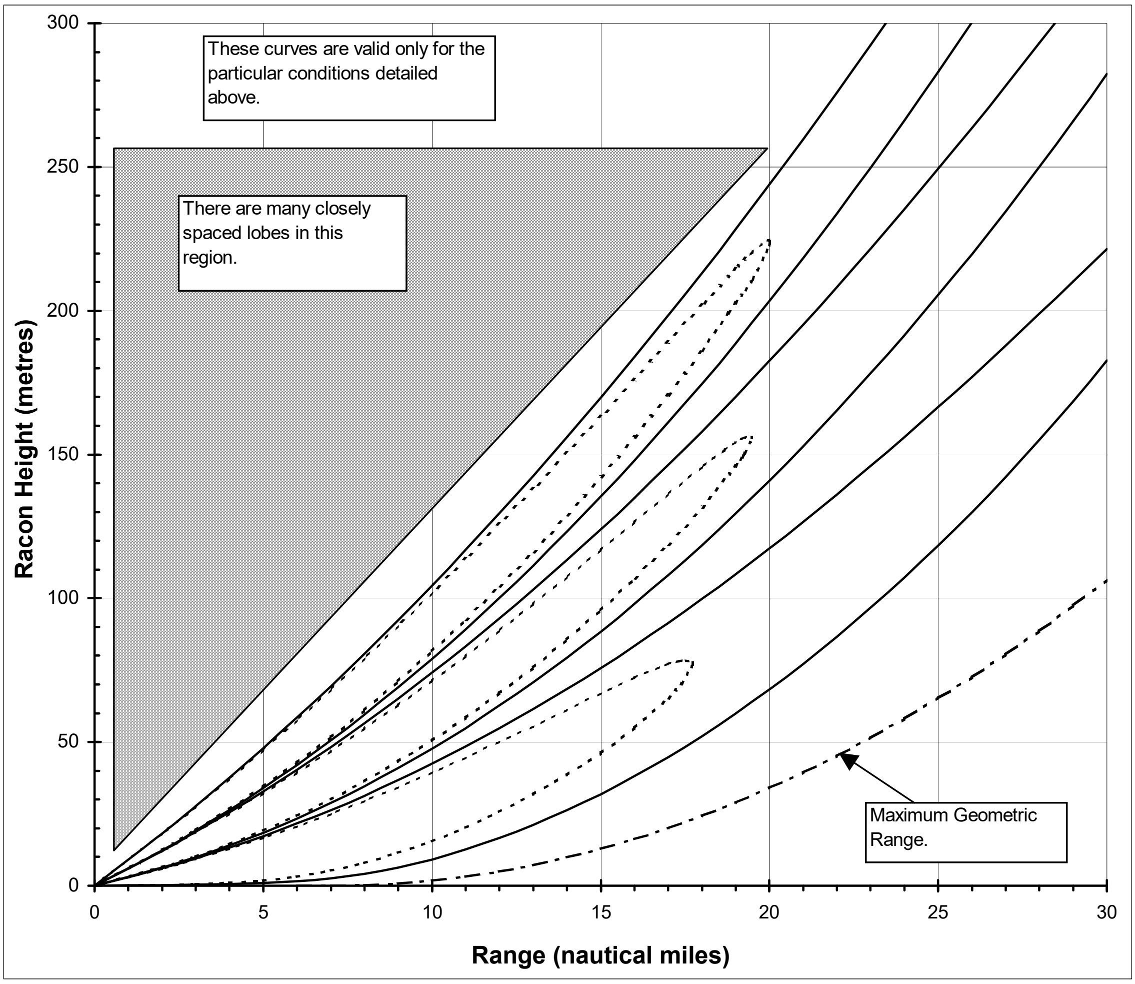
Racon Parameters:

Power	1	watt
Antenna Gain	4.5	dBi
Receiver Sensitivity	-40	dBm

Critical Path: Radar to Racon

Environment:

Refraction Constant (k)	1.33	
Wave Height	0	metres (crest to trough)



The graph shows the maximum geometric range and the first three lobes caused by multipath effects due to reflection at the sea surface, plotted as a function of racon height above sea level. Interference nulls are also present above the third lobe, but are generally only of small range duration. To use the graph, enter with racon height (assumed to be the same as the associated light if not specifically quoted) and read off the maximum detection range and the ranges at which signal loss due to the multipath effects will be experienced. The curves inside the main lobes are calculated for a 6 dB loss of performance and indicate the range reduction if such losses are present.

Figure 5 RACON range diagram – 9.4 GHz (Table 1, 2B)

A 6. LARGE COMMERCIAL (RADAR ANTENNA HEIGHT 15 m)

Vessel Type: Large Commercial (Radar Antenna Height 15 metres)

Radar Parameters:

Power	25	kW
Antenna Gain	31	dBi
Receiver Sensitivity	-95.5	dBm

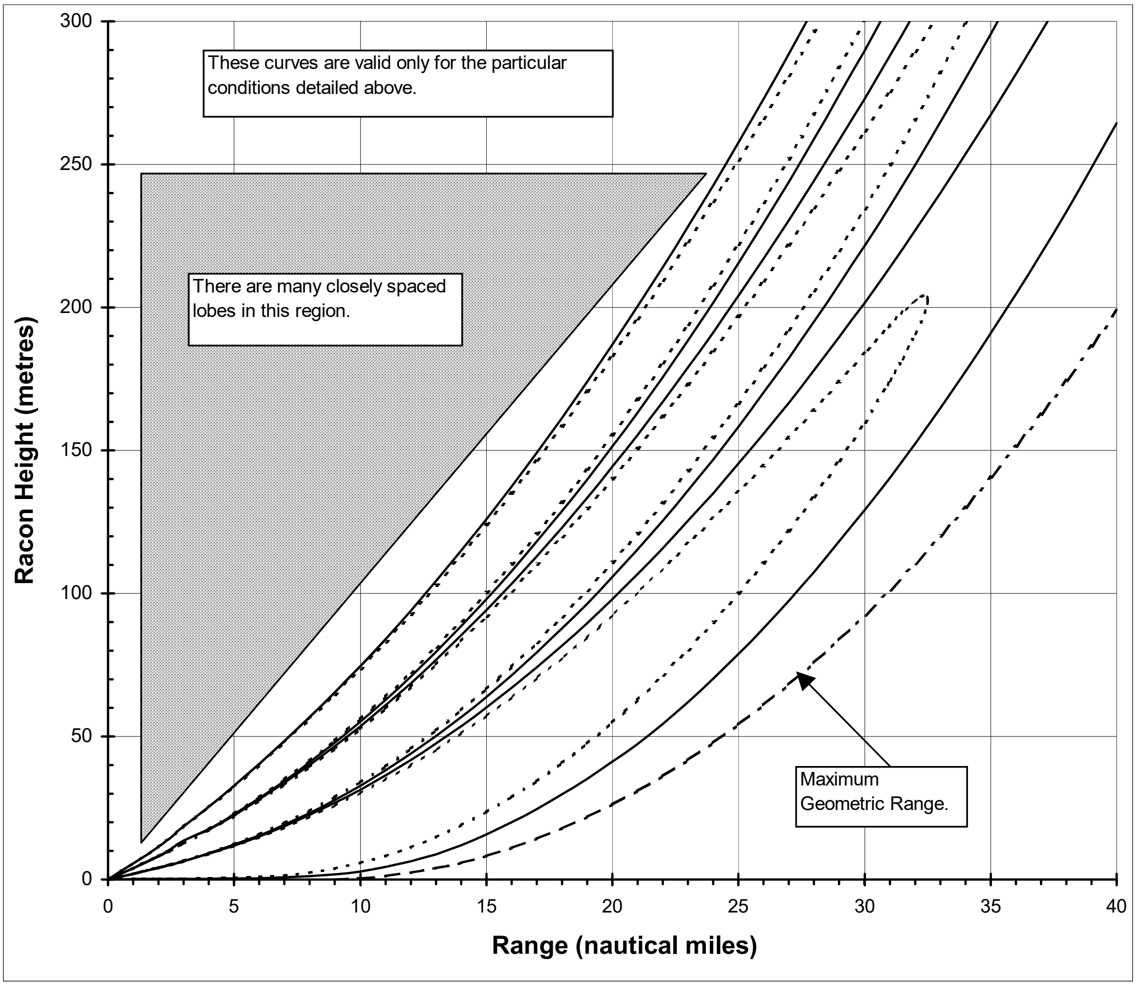
Racon Parameters:

Power	1	watt
Antenna Gain	4.5	dBi
Receiver Sensitivity	-40	dBm

Critical Path: Radar to Racon

Environment:

Refraction Constant (k)	1.33	
Wave Height	0	metres (crest to trough)



The graph shows the maximum geometric range and the first three lobes caused by multipath effects due to reflection at the sea surface, plotted as a function of racon height above sea level. Interference nulls are also present above the third lobe, but are generally only of small range duration. To use the graph, enter with racon height (assumed to be the same as the associated light if not specifically quoted) and read off the maximum detection range and the ranges at which signal loss due to the multipath effects will be experienced. The curves inside the main lobes are calculated for a 6 dB loss of performance and indicate the range reduction if such losses are present.

Figure 6 RACON range diagram – 9.4 GHz (Table 1, 3A)

A 7. LARGE COMMERCIAL (RADAR ANTENNA HEIGHT 35 m)

Vessel Type: **Large Commercial (Radar Antenna Height 35 metres)**

Radar Parameters:

Power	25	kW
Antenna Gain	31	dBi
Receiver Sensitivity	-95.5	dBm

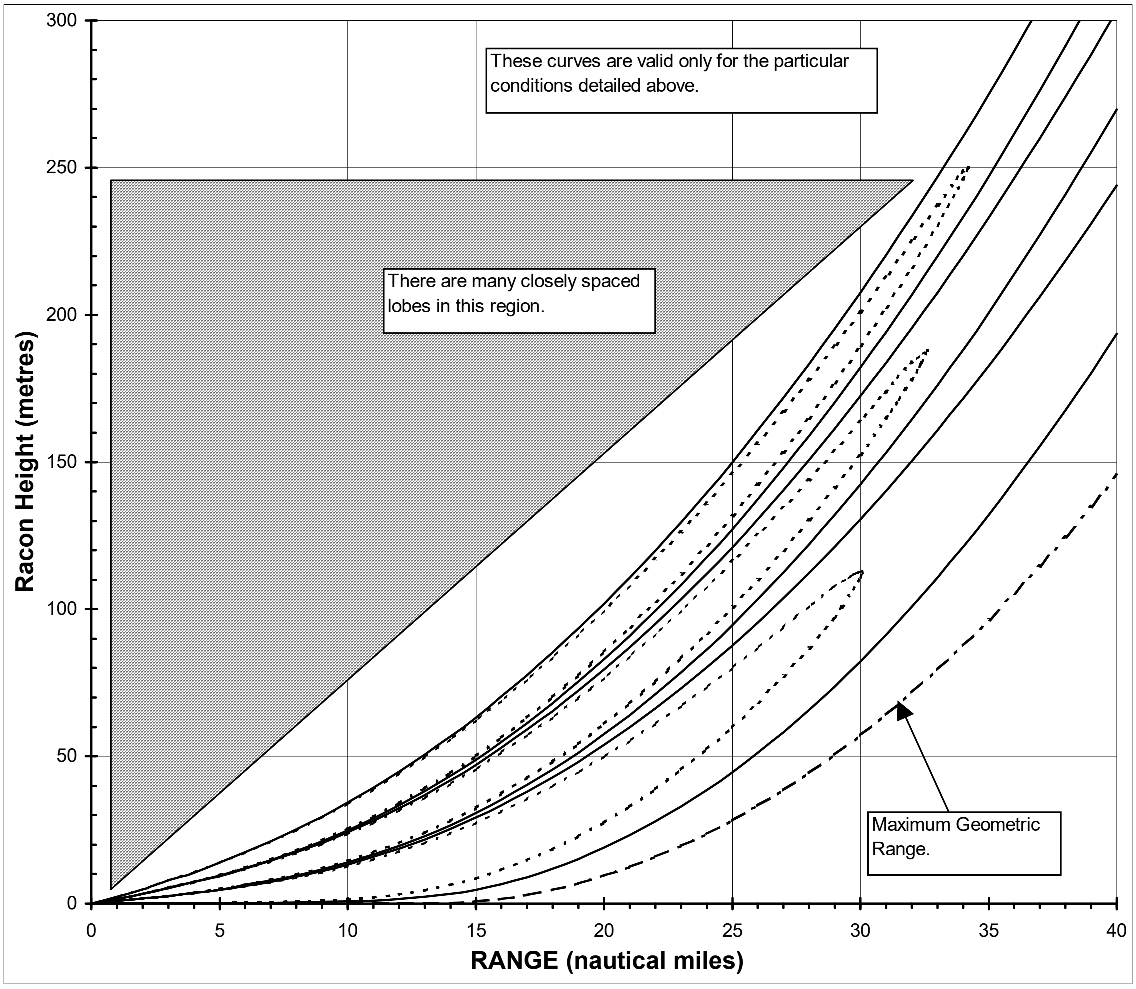
Racon Parameters:

Power	1	watt
Antenna Gain	4.5	dBi
Receiver Sensitivity	-40	dBm

Critical Path: Radar to Racon

Environment:

Refraction Constant (k)	1.33	
Wave Height	0	metres (crest to trough)



The graph shows the maximum geometric range and the first three lobes caused by multipath effects due to reflection at the sea surface, plotted as a function of racon height above sea level. Interference nulls are also present above the third lobe, but are generally only of small range duration. To use the graph, enter with racon height (assumed to be the same as the associated light if not specifically quoted) and read off the maximum detection range and the ranges at which signal loss due to the multipath effects will be experienced. The curves inside the main lobes are calculated for a 6 dB loss of performance and indicate the range reduction if such losses are present.

Figure 7 RACON range diagram – 9.4 GHz (Table 1, 3B)

A 8. SMALL CRAFT (RADAR ANTENNA HEIGHT 3 m)

Vessel Type: **Small Craft (Radar Antenna Height 3 metres)**

Radar Parameters:

Power	4	kW
Antenna Gain	25	dBi
Receiver Sensitivity	-95.5	dBm

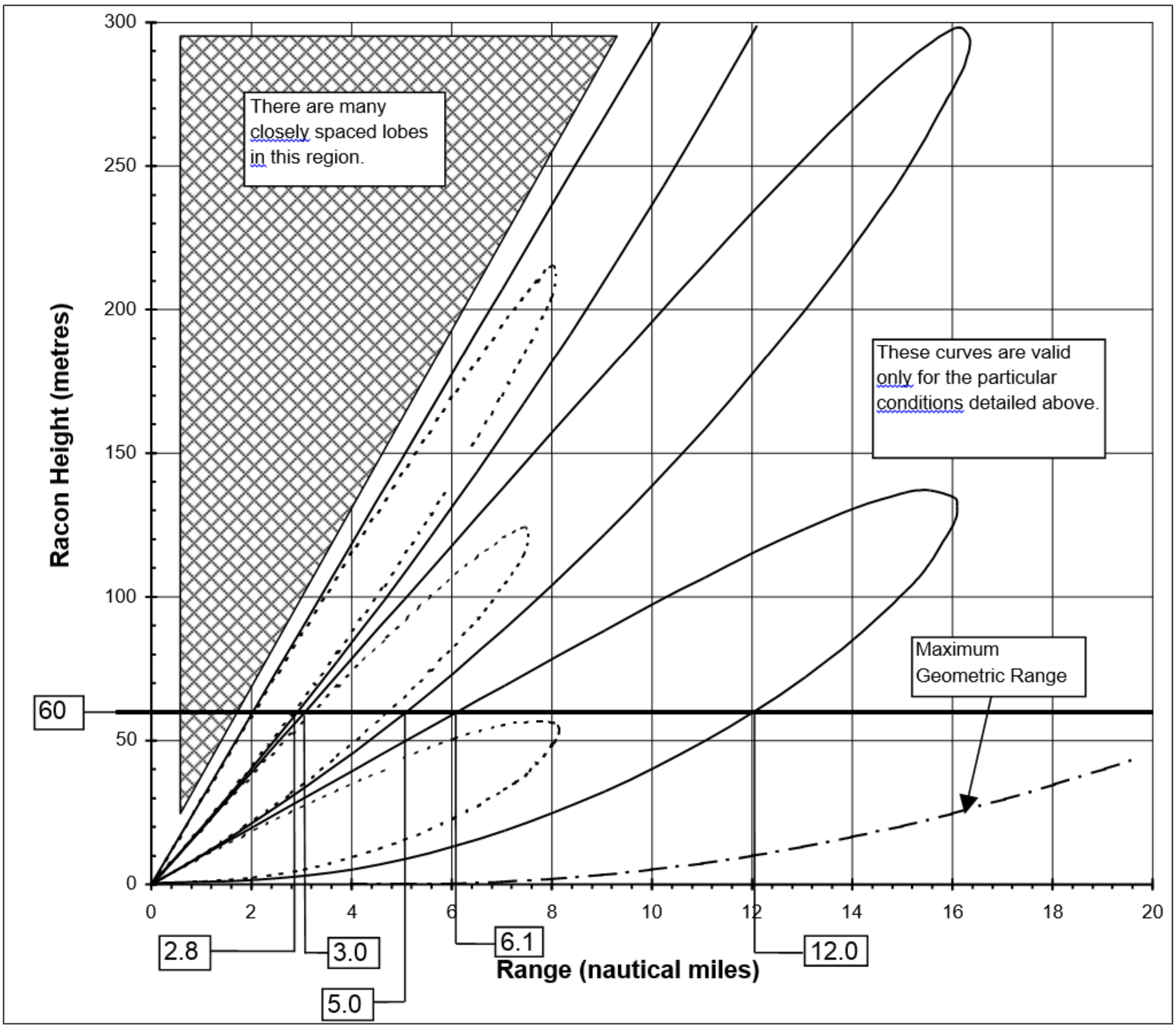
Racon Parameters:

Power	1	watt
Antenna Gain	4.5	dBi
Receiver Sensitivity	-40	dBm

Critical Path: Radar to Racon

Environment:

Refraction Constant (k)	1.33	
Wave Height	0	metres (crest to trough)



Example of Finding Maximum Range and First Two Null Areas

Figure 8 RACON range diagram – 9.4 GHz (Table 1, 1A)

A 9. EXPECTED RACON RANGE

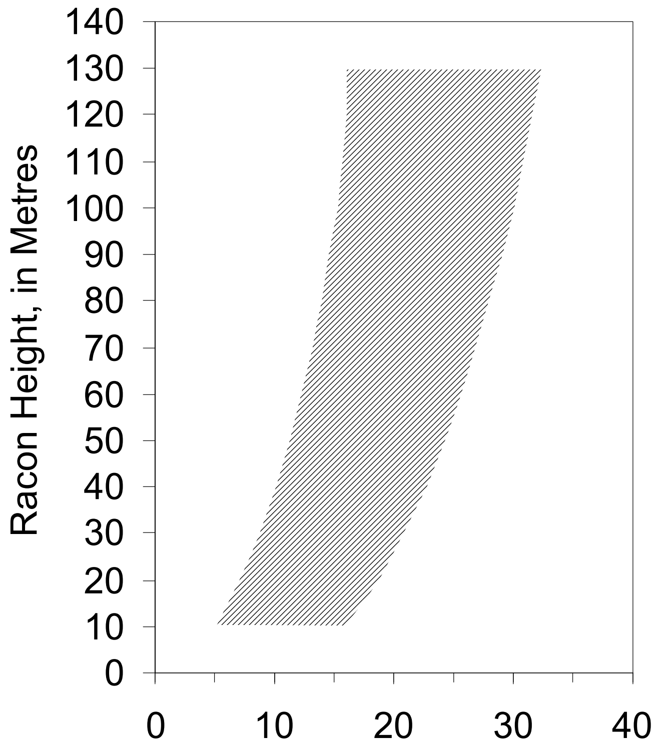


Figure 9 Expected RACON range, in nautical miles

The left edge of the shaded area represents the expected distance for a small vessel using a 4 kW radar with its antenna mounted at 3 m above sea level. The right edge of the shaded area represents the expected distance for a large vessel using a 25 kW radar with its antenna mounted at 35 m above sea level. Figure 9 can be used in two ways. The first is for determining range for a RACON that is already installed. For example, a RACON height of 60 m would yield an expected range of 12 NM to about 26 NM. The second use of the chart is for planning. For example, the goal is to service primarily large vessels at 25 NM and secondarily small vessels at 10 NM. RACON mounting height of greater than 40 metres would be expected to accomplish both goals.

ANNEX B DISCUSSION ON TRACKING ACCURACY AND EFFECT ON RACON RANGE

The Guidelines state 'the strength of the radar signal received at the RACON is more critical than the return path and determines whether the RACON will transmit a response.'

In determining the critical path, figures-of-merit (FOM) are computed. FOM have very little absolute value (for example, they cannot tell you maximum range), but are useful for comparison. For the interrogation path, FOM is calculated using radar power, gain for both radar and RACON antennas and RACON receiver threshold values. For the response path, FOM is calculated using RACON power, gain for both radar and RACON antennas and radar receiver threshold.

For example, assume the following RACON characteristics:

Receiver Threshold:	-40 dBm
Transmitter Power:	1 Watt
Antenna Gain:	4.5 dBi

Further assume the following radar characteristics (Table 1, 3A):

Receiver Threshold:	-95.5 dBm
Transmitter Power:	25 kWatt
Antenna Gain:	31 dBi

For this radar/ RACON combination, calculated FOM values are:

Interrogation FOM:	149.5 dB
Response FOM:	161 dB

These FOM indicate that the response path is 11.5 dB 'better' than the interrogation path. This means that if the interrogation is detected by the RACON, the radar will detect the response. RACON manufacturers ensure this by design, with a combination of RACON transmission characteristics such as transmitter power, antenna gain and transmitted frequency (or, tracking) accuracy.

There is an implication that the response path can 'degrade' by as much as 11.5 dB and the radar will still detect the RACON's response. For example, changing the RACON transmitter power from 1 Watt to 100 mW (30 dBm to 20 dBm) reduces the response FOM by 10 dB, but does not change the RACON operating range because the response FOM is still greater than the interrogation FOM.

To this point, perfect tracking accuracy has been assumed. Individual radars transmit at various frequencies within the band. For a RACON to be detected by a radar, the RACON needs to respond at that radar's frequency. The process of measuring the radar frequency and adjusting the RACON transmission frequency to match is not perfect and some error in frequency tracking can be expected.

RACON tracking error appears to degrade the response signal at the radar receiver. In order to quantify the amount of degradation, the input filter parameters of the radar receiver input characteristics are needed.

Radar receivers have narrow band pass filters to exclude signals that are not wanted. A typical radar might have the following input filter parameters (when using long radar pulses, which is the worst case, as the narrowest receiver filter is used):

3 dB down at 1.5 MHz away from centre frequency

Roll-off of 2.5 dB/MHz

As an approximation, the roll-off value is used. This means that for every 1 MHz of tracking error, the RACON signal is degraded by 2.5 dB. Referring to the comparison between interrogation and response FOM, this implies that a tracking error of 4.6 MHz [11.5 dB/(2.5dB/MHz)] could be tolerated with no loss in RACON range. As another example, a tracking error of 10 MHz could result in a loss of range of about 13.5 dB [(10 MHz)(2.5 dB/MHz) – 11.5 dB], or more than 75%.

These problems essentially disappear when using short radar pulses or operating at close distances. When operating with short radar pulses, radar receiver filters are wider in order to accept the short pulse returns. This one reason why IALA R-101 Recommendation on Radar Beacons (RACONs) recommends a larger tolerance for tracking accuracy for short pulses compared to long pulses. In all cases, the power of the response from the RACON is huge in comparison to radar target reflections.

The following chart lists the FOM for the three different X Band radars from the Guidelines, and shows the calculated loss in range for various tracking errors. Receiver filter characteristics are assumed to be as used above.

Table 3 Calculated loss in range for various tracking errors

				Loss of Range		
Power	**Antenna Gain**	**Interrogate FOM**	**Response FOM**	**2 MHz Error**	**5 MHz Error**	**10 MHz Error**
4 kW	25 dBi	135.5	155	NONE	NONE	41%
10 kW	29 dBi	143.5	159	NONE	NONE	68%
25 kW	31 dBI	149.5	161	NONE	11%	79%