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Project RAND

(U) STUDY OF LAUNCHING SITES FOR A SATELLITE PROJECTILE

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* This initial external distribution list includes the distribution of all related technical reports on the satellite vehicle.

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SUMMARY

A discussion is given of the factors which enter into the choice of a launching site for the first experimental satellite. Reasons are adduced for launching eastward from some point within 2° of latitude of the equator. With the problem thus restricted, thirteen equatorial sites, two in South America, three in Africa, seven in the Indonesian Archipelago, and one in the Southwest Pacific, are discussed in relation to desirable physical features.

By a process of elimination it is shown that a location in the Indonesian Archipelago is probably the best that can be found, with a site on the island of Halmahera in the Moluccas as a good detailed selection in that region. A good second choice lies in the same general region on the eastern coast of Borneo.

No detailed account is taken of international political problems other than safety of foreign persons and property.

February 1, 1947

STUDY OF LAUNCHING SITES FOR A SATELLITE PROJECTILE

I. INTRODUCTION

Other reports of this series[1,2,3,4] discuss the construction, operation, tracking, and control requirements of a man-made satellite. In these reports it is made apparent that economies of various kinds are essential if a satellite is some day to be launched[5]. It is the purpose of this report, by pointing out the general requirements for launching sites, and by discussing the feasibility of several possible sites, to assist in making economies, and to aid in the selection of a launching site for the first experimental satellite.

A satellite rocket using chemical fuels is multi-staged. In contrast with a V-2 rocket, which is assembled in a horizontal position and raised to a vertical position before fueling, a satellite rocket will be assembled in the vertical position, fueled, and fired[3]. After take-off, the rocket will rise vertically for a few thousand feet then tilt in the direction of the final orbit. At intervals of slightly less than two minutes the fuel supply will be exhausted in the first and second stages and they will be dropped off. A long coasting period will be inserted in the third stage, and the final thrust, lasting about fifteen seconds, will take place some fifteen minutes and 2500 miles from the launching time and location. The free orbital motion which will commence at this time will be at an altitude of about 350 miles, and the corresponding velocity will be about 23,000 feet per second. For a complete description of the launching trajectory see ref. 1.

The barest requirements for a launching site are an accessible, reasonably flat piece of ground of a few acres extent. Geographically such a site may be found almost anywhere. A complete launching operation requires in addition to a suitable launching site a chain of at least four radar stations extending beneath the launching trajectory to a distance of some 2700 miles from the launching site[4]. Radar stations, for successful operation, require a stable platform, preferably a piece of land. The mere suitability of a particular site for launching is therefore insufficient for the establishment of a satellite. Suitable sites for radar stations under the launching trajectory must also be available.

II. CHOICE OF AN EQUATORIAL ORBIT

It is anticipated that satellites will eventually be put to a variety of uses, both scientific and military, some of which are described in ref. 6. According

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For references see page 49.

to the intended use, a given satellite may be placed upon a north-south, oblique, or equatorial orbit. A basic characteristic of all these orbits is that (except for a slow precession which does not affect the present discussion) the orbit plane includes the center of the earth and maintains a fixed direction in space while the earth rotates on its own axis. The period of revolution of such a satellite is about 1½ hours. The only orbit, therefore, which allows the satellite continually to retrace the same path in projection on the earth's surface is an orbit in the plane of the earth's equator. This fact has already been pointed out in ref. 7. An orbit passing over the poles has interesting possibilities in the way of applications, provided observing stations and stations for communication reception from the satellite can be located at one or both of the earth's poles. At present this would be for all practical purposes a prohibitive undertaking. It should be pointed out however that the launching for a transpolar orbit need not take place from either pole.

There is little doubt that the first satellite will be devoted entirely to measuring characteristics of, and physical processes taking place in, the upper air. As a part of that activity, in addition to telemetering data from the satellite, it will be necessary to record the position of the satellite continuously for a few revolutions at least. To insure the reception of data at frequent intervals, with a reasonable number of ground stations, it is necessary to employ the orbit which retraces its ground track, i.e., an equatorial orbit. Since even the characteristics of the upper atmosphere vary with latitude, subsequent satellites can extend the atmospheric survey by operating on oblique orbits, with the understanding that relatively infrequent data can be recorded, unless a method of accumulating or storing information for occasional rapid transmission can be developed.

As described in ref. 1, launching in an easterly direction from the equator enables the rocket to take full advantage of the earth's speed of rotation (1520 feet per second) in reaching its orbital velocity. Computation has shown that the equatorial vehicle can be built for 30% less gross weight than a similar rocket which moves on a north-south orbit. In terms of monetary cost, such a saving would undoubtedly pay for an equatorial launching installation several times over; see ref. 5 for curves of cost versus gross weight.

For the first satellite to be placed on an orbit above the equator, it will be necessary to have the launching site near the equator, say within about two degrees of latitude. So long as the launching is in a true easterly direction at 2° from the equator, or as long as the maximum distance the satellite reaches north and south of the equator is not more than about 2° of latitude, a single chain of tracking stations and receiving stations for the telemetered information will suffice. Launchings from greater distances from the equator would mean that the rocket would have to be maneuvered onto the equator after take-off. Such a procedure, regardless of the exact trajectory followed, would be extremely wasteful of rocket fuel and would add enormously to the size and cost of the rocket required.

It has been pointed out that some very high mountains exist close to the equator, in Ecuador (Mt. Cotopaxi, elevation 19,500 feet), and in central and eastern Africa (Mt. Ruwenzori, elevation 16,800 feet, and Mt. Kenya, elevation 17,000 feet). The suggestion has been made that launching from the slopes or summits of mountains would reduce the total drag experienced by the rocket by avoiding passage through the lowest and most dense three or four miles of the atmosphere. Such a launching would also reduce the necessary climb by three or four miles. Calculations have shown that the saving in gross weight resulting from an equatorial launching from 10,000 feet versus a sea-level launching is only about 3%. This small gain could scarcely offset the cost and effort of establishing a launching site at such an elevation. In fact the equatorial mountains are particularly inaccessible.

III. REQUIREMENTS OF AN EQUATORIAL LAUNCHING SITE

In its detail any launching site, wherever situated, should provide an open area which is reasonably level, and large enough to permit storage, assembly, fueling and launching. Such a site should contain or be near places suitable for living quarters, shops, power station, and communications facilities. It is very probable that sufficient land should be available for an airstrip. V-2 launching site requirements provide a useful guide.

a. Accessibility

Accessibility of an equatorial launching site is largely a geographical matter. Most of the equatorial land areas are undeveloped, and, in fact, covered by thick rain forest. Roads and railways are nearly always absent, and the principal means of access is by ship along coasts and up the navigable rivers such as the Amazon of South America which, with its tributaries, is navigable for thousands of miles. In a few instances accessibility by air will be possible, particularly in regions where United States Armed Forces operated during the recent war. Apart from the possible establishment of tracking stations, aircraft are likely to be inadequate as the sole means of transportation to the launching site. The equatorial islands of the Pacific and Indian Oceans, and the coasts of the islands of the Netherlands East Indies are quite accessible to ships, though landings are sometimes difficult to effect, particularly on some of the Pacific islands.

Though it is probable that the launching expedition would have to be self-contained with regard to quarters, power, technical facilities, and electrical communications, the local availability of any of these items should be examined. An entirely self-contained expedition is convenient, but expensive. World War II operations in the Pacific area have resulted in much valuable experience in the organization and conduct of such expeditions.

b. Climatological and Meteorological Suitability

1. General

The suitability of a launching site from climatological and meteorological considerations is a very complex subject, and it is of importance to practically every aspect of a launching operation. In the last analysis the actual moment of launching must be determined by the suitability of the prevailing meteorological situation. Clearly it would be hazardous to attempt the launching in a high wind or at a time when sporadic gusts of wind are likely. This is amply borne out by experience with V-2 launchings. Granted relatively quiet conditions on the ground, it would be unwise to launch the satellite at a time when the first few miles of expected flight would pass through a heavy cumulus cloud. Such clouds frequently contain regions of tremendous turbulence and sometimes contain hail. The latter is capable of causing serious damage to the skin of the satellite. Finally it would not be proper to launch the satellite during a rain. Rain will give rise to additional and unallowed-for drag and could easily impair the functioning of the rocket in other ways.

2. *Comfort and Health*

The climate of the equatorial zone of the earth is in general characterized by high temperature and humidity. From the health and comfort aspects of the personnel participating in the launching operations, it is desirable to find the coolest and driest possible location. The most suitable regions from the comfort point of view are certain of the Pacific islands, and the highlands of Kenya. The worst extensive regions for both comfort and health lie in West and Central Africa, and in the Amazon valley. There is considerable variation in the Netherlands East Indies.

3. *Molds and Fungi*

For the most successful operation and maintenance of electronic equipment both in the satellite (before launching), and on the ground, it is desirable to avoid long exposure to excessive humidity at temperatures prevailing near sea-level in the tropics. Under such conditions particularly troublesome types of mold flourish in and on many types of components in electronic equipment, and insulation becomes a very difficult problem. The fungus problem and "tropicalization" to minimize fungus troubles were intensively studied during World War II, and while much progress was made, it is still unwise to invite trouble by lack of proper precautions such as air-conditioning. Jungle areas are the worst for fungus difficulties.

4. *Atmospherics*

The operation of high frequency (3 to 30 megacycle) communications equipment is subject to considerable interference from atmospherics resulting, in the tropics particularly, from thunderstorms. Thunderstorms are prevalent in certain areas of the equatorial zone at certain seasons and these areas constitute notorious sources of heavy atmospheric interference. This subject will be of importance to the intercommunications system between the launching site and the tracking radars. Estimates of the extent of this interference and its effect on various types of communication will be found in refs. 8 and 9. Figs. 1,2,3, and 4 show the locations of the more important tropical thunderstorm regions.

While the electronic equipment used for observing and tracking the satellite, and communication between the satellite and ground stations, will operate at ultra-high frequencies, it would be unwise to launch the satellite at a time when a thunderstorm was occurring in the immediate vicinity, or perhaps even within 10 to 15 miles. The noise disturbance in a receiver produced by a lightning discharge varies inversely as the frequency. Measurements on 150 megacycles have shown that a lightning stroke at a distance of five miles can produce a disturbance of five microvolts per meter at a receiver having a reception bandwidth of 1.5 megacycles[10]. A receiver having the same band-

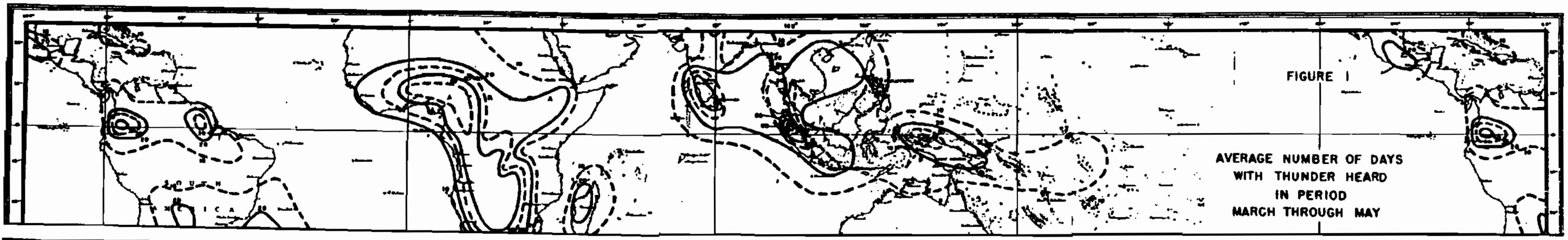

FIGURE 1

AVERAGE NUMBER OF DAYS
WITH THUNDER HEARD
IN PERIOD
MARCH THROUGH MAY

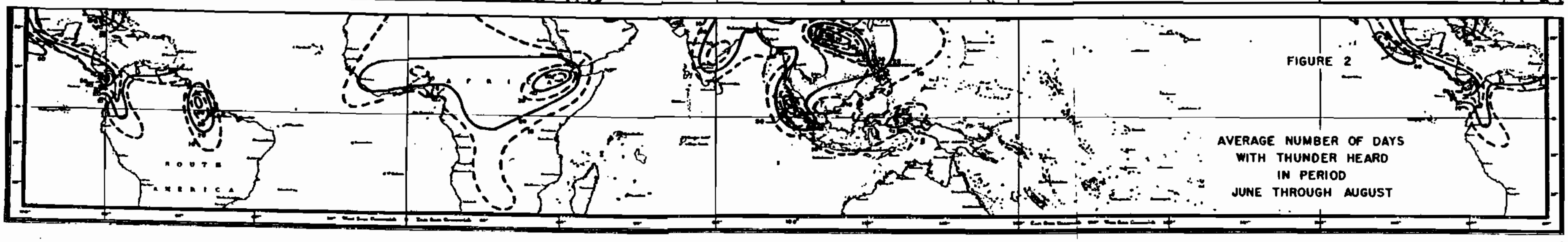

FIGURE 2

AVERAGE NUMBER OF DAYS
WITH THUNDER HEARD
IN PERIOD
JUNE THROUGH AUGUST

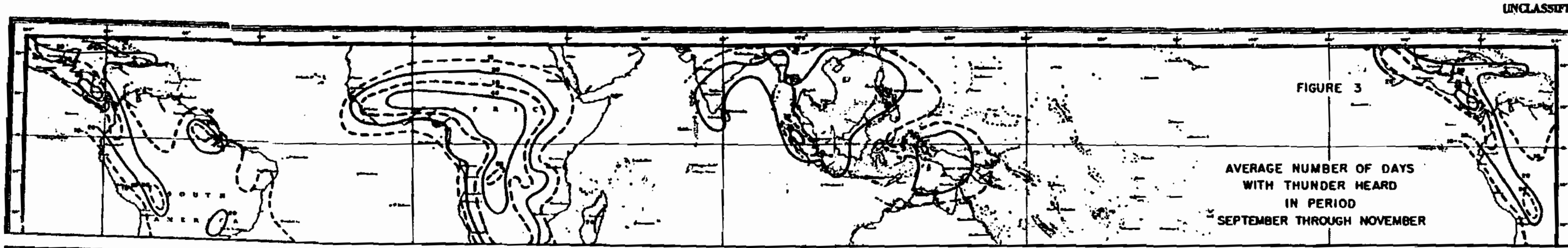

FIGURE 3

AVERAGE NUMBER OF DAYS WITH THUNDER HEARD IN PERIOD SEPTEMBER THROUGH NOVEMBER

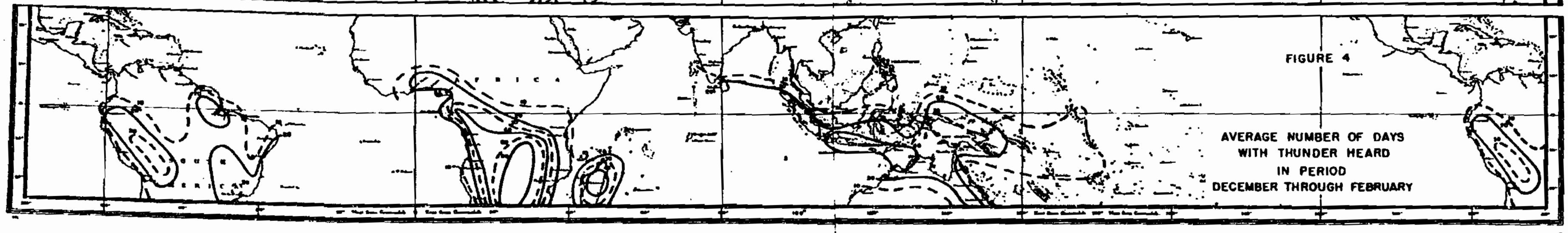

FIGURE 4

AVERAGE NUMBER OF DAYS WITH THUNDER HEARD IN PERIOD DECEMBER THROUGH FEBRUARY width but operating at 1500 megacycles and situated 10 to 15 miles away from the same lightning discharge would receive less than 0.1 microvolts per meter, which is less than the other kinds of receiver noise which will be found for the same bandwidth and frequency.

5. *Optical Tracking*

Since it is very likely that a launching would be observed optically as well as by radar, it is desirable to have as clear a sky as possible. Completely cloud-free skies are rare in the equatorial zone; on the other hand "fine weather" is not uncommon at certain seasons and at certain times of day. In Section IV below a brief climatological and meteorological survey of the equatorial zone will be made.

c. Security Considerations and Political Feasibility

An equatorial satellite launching operation including the tracking and command control[4] during powered flight cannot be carried out entirely on United States territory or on land under present United States control. The only territory owned by the United States within 2° of the equator consists of three very small islands (Howland, Baker, and Jarvis) in the central Pacific. The largest of these is less than three square miles in area. None has a harbor, or fresh water supply. Christmas Island, in the central Pacific and near Jarvis Island, is a fine island, and has a land surface about equal to Oahu; the United States is said to dispute title to this island with Great Britain. To these islands may be added Kapingamarangi or Greenwich Islands, an atoll group, formerly mandated to Japan, located somewhat to the south of the Caroline Group. Because of this dearth of suitable United States territory near the equator, some of the launching operation, and most of the orbital tracking will have to be done from foreign territory, and any strict secrecy about a launching operation will be difficult.

The subject of the political feasibility of launching a satellite from territory belonging to other countries will not be discussed in this report. Table 1, which follows, gives the list of countries, besides the United States, controlling land lying within 150 miles of the geographic equator.

Table 1

Netherlands	Venezuela
Great Britain	Brazil
Australia	Spain
Japan (formerly)	Portugal
Ecuador	France
Peru	Belgium
Colombia	Italy (formerly)

d. Remoteness from Concentrations of Population

All the larger land areas over which the equatorial satellite will pass contain some population, but in almost all places the population density is low. Because of the risks attendant on launching, it would be unwise to choose a launching site in the immediate vicinity of a large city or town. The probability of the satellite causing harm to human beings and their property when it comes down is so minute as to be negligible. There is less than one chance in four that the satellite, when it descends, will descend on land.

The only large city within 150 miles of the equator is Singapore, population about 600,000, and a launching near that city should be avoided. Other moderate cities or towns within this limit are in order of population Belém (Brazil), Guayaquil (Ecuador), Quito (Ecuador), Nairobi (Kenya), Mogadiscio (Somaliland), Entebbe (Uganda) and Libreville (French Equatorial Africa).

IV. CLIMATOLOGICAL SURVEY OF THE EQUATORIAL ZONE

a. General

In an earlier section it was shown that the ideal satellite launching site ought to be dry and cool, and free of excessive wind. Furthermore the sky should be free of cloud. Unfortunately the equatorial region of the earth does not contain any such ideal place. It is usually neither dry nor cool, and while winds are for the most part gentle, considerable winds sometimes accompany thunderstorms on land, and doldrum belt squalls at sea. Some parts of the equatorial region are subject to large scale cyclonic storms. Equatorial skies are seldom, if ever, cloud-free. The most that can be done is to choose a site which minimizes these difficulties, and then use particular care to select the correct launching season.

The comparative meteorology or climatology of the earth has been studied by many persons, and ref. 11 contains a particularly complete survey of the position as of 1928; it includes in summary form the results on the world distribution of thunderstorms as determined by Brooks and published in his well-known and frequently quoted memoir of 1925[12]. Ref. 13 is much more recent and contains some revision of the published Brooks results, but like the earlier works it lacks the definiteness which is really required for this report. Ref. 14 contains a useful compilation of data which show diurnal and seasonal variation of thunder, and is a particularly useful guide to the Netherlands East Indies region.

b. Oceanic Climate - Doldrums

In general the climate of a particular location in the equatorial zone is determined by the seasonal wanderings of the doldrum belt or, as it is sometimes called, the "inter-tropical front". The nature and characteristics of the doldrum belt are described in detail in the Appendix to this report, which is reproduced directly from refs. 15 and 16. Figs. 6 through 17 of the Appendix show the mean monthly positions of the doldrum belt as it makes its seasonal migration. Doldrum phenomena are only really clear-cut and readily discerned in oceanic regions, and the material in ref. 16 is based primarily on a very thorough study of ships' logs through 1942 available to the British Admiralty. This particular study is almost certainly the most complete of its kind yet made.

The doldrum belt is a region of low barometric pressure lying between the trade wind belts. It is characterized by day by very calm air most of the time, but with occasional squalls, and very high humidity. The sky is generally overcast, though some weak sunlight occasionally penetrates the thin cloud. The temperature is generally high. At night the region becomes unstable by virtue of radiation from the top of the cloud mass. The high specific heat of the ocean holds the air temperature very constant near the surface of the sea. By midnight, the cool top air begins to sink and the hot moist surface air is displaced upward with sufficient rapidity to give rise to precipitation and occasional thunderstorms. With sunrise the top of the cloud layer quickly absorbs sufficient heat to restore equilibrium and the thunderstorms and rain cease. The maximum storminess in the doldrum belt generally occurs at sunrise. Doldrum weather is mainly oceanic but is often noted in coastal regions and in particular in regions like the Netherlands East Indies which show both doldrum and continental characteristics. In general the atmosphere is most stable, and therefore most suitable for satellite launching in and near the doldrum belt from about 0900 to 1200 local time.

c. Continental Climate

The doldrum belt is still roughly discernable over the continental areas in the tropics, and is in fact indicated over land masses in Figs. 6 through 17 of the Appendix. The monsoon rains of India and Burma are merely a manifestation of the doldrums. The causes and times of occurrence of rain, thunder and cloud over land areas are very different from those over oceanic regions. In the morning the sun beats down on the ground and raises the surface temperature considerably - in contrast with the very slow rate of heating the ocean, the surface temperature of which shows an almost imperceptible diurnal variation. This in turn heats the surface air. By midday convection becomes vigorous, and towering cumulus begins to form. By midafternoon the instability is such that precipitation often accompanied by thunder takes place. At night the skies tend to clear and the ground then radiates its excessive heat into space. Convection-produced rain and thunder of this type is most likely to take place in the afternoon, and is least likely in the forenoon.

The presence of mountainous areas in the tropics (and elsewhere at times) gives rise to another type of precipitation and thunder, caused by orographic ascent, i.e., the forcing of low lying moist air to rise and cool adiabatically in order to pass over the mountains. The rain and thunder come about from the cooling and the turbulence around the mountains. Individual mountain peaks often act like chimneys and collect cloud caps and rain. This type of rain and cloud formation frequently lasts all night in a less violent condition. Depending upon local conditions there is sometimes a relatively clear dry area on one side of a mountain range.

Thunderstorms over land are frequently accompanied by fairly strong advective winds, particularly just before the onset of the rain, and are for that reason alone a source of hazard to the launching operation. In general over fairly level equatorial land areas there are at most only light winds.

During the recent war Dr. C. E. P. Brooks was asked to revise his published thunderstorm maps[12]. Figs. 2 and 4 show the contours of number of days with thunder heard in the world's thunder regions according to Dr. Brooks' revised charts at the extreme seasons. As these results are more recent, though not available in published form, it seemed worthwhile to include them in this report. The data they represent are known to be more extensive than those represented in ref. 12, and are likely to be more extensive than those represented in ref. 13.

From what has been said thus far, and from an examination of Figs. 1 through 4, and 6 through 17 it is possible to arrive at the following generalizations:

1. The best months for launching at nearly all possible equatorial locations are July and August*, though January and February may well prove to be suitable at several possible sites.

2. The best chances for favorable weather occur between the hours of 0900 and 1200 local time. Since the launching trajectory passes to the east of the launching site, or over areas of progressively increasing local time, it is advisable to launch the satellite on the chosen day as soon after 0900 local time as possible.

V. DISCUSSION OF INDIVIDUAL SITES

In this section a series of possible launching sites is considered in the light of the earlier discussion. It will be tacitly assumed that the necessary arrangements can be made for the use of the foreign territory involved. Beyond the following discussion, the next logical step would come after a decision had been made to launch a satellite and would consist of making a highly detailed investigation of sites, and an on-the-spot survey in connection with actual launching preparations.

An actual launching involves a minimum of five separate sites, the launching site itself, designated henceforth as L in the discussion and on Fig. 5, and four sites for radar tracking and reception of telemetered data during launching. The latter four stations are strung out under the launching trajectory, and are designated in their order from L as H_1, B_1, B_2, and H_2 in accordance with ref. 4. Ideally these stations should be placed along the equator at the distances, to the east of L, shown in Table 2 below, but their exact positioning is not so critical as might be supposed. When suitable land at the ideal position is not available, it is permissible to locate these stations within a circle about the ideal position of radius indicated in the third column of the table. These tolerance circles, which are eccentrically located, are somewhat arbitrary, and were chosen in such a manner that the favorable geometry of observation would be fairly well preserved.

*The fact that the Perseid meteor shower reaches its maximum in August should probably occasion no serious concern about a significant increase in the probability of a meteor collision with the satellite, although this fact may constitute grounds for holding the launching sometime in July. See ref. 7.

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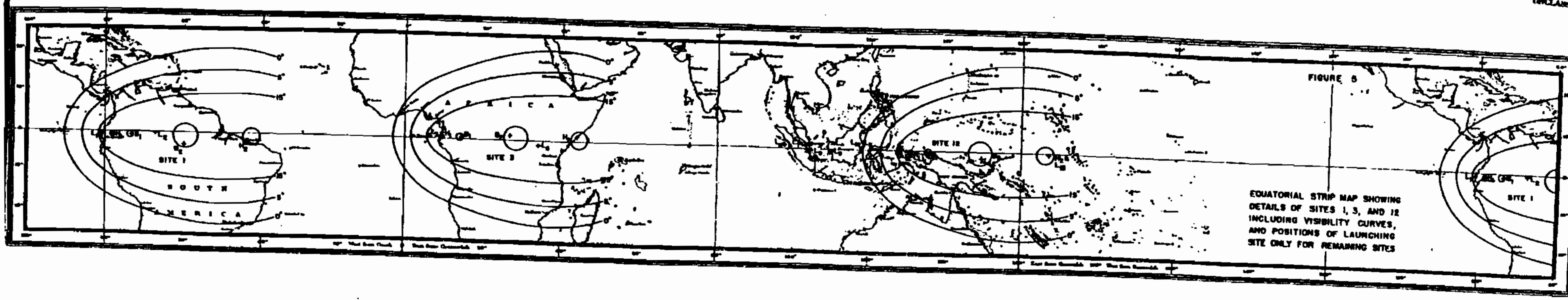

FIGURE 5

EQUATORIAL STRIP MAP SHOWING DETAILS OF SITES 1, 3, AND 12 INCLUDING VISIBILITY CURVES, AND POSITIONS OF LAUNCHING SITE ONLY FOR REMAINING SITES

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Table 2

Station	Ideal Distance from L (statute miles)	Radius of Tolerance Circle (statute miles)	Distance from L to Center of Tolerance Circle (statute miles)
H_1	200	25	200
B_1	500	50	525
B_2	1400	200	1500
H_2	2700	150	2650

On the assumption that the inclination of the satellite orbit to the earth's equatorial plane will not exceed 2°, the matter of the radar and optical visibility of the satellite rocket during the launching operation has been investigated. Fig. 5 shows the entire equatorial belt of the earth. Points L_1 through L_{13} show the possible launching sites discussed in the catalogue below. With three of these possible launching sites L_1, L_2 and L_{13}, are also shown the associated radar and telemetering sites, H_1, B_1, B_2, and H_2 as designated in ref. 4. Around these three strings of sites are curved lines including the areas within which the satellite rocket will have a maximum apparent elevation of 15°, 5°, and finally the area within which the rocket is just visible at the horizon at sometime during the launching operation. These curves apply, of course, to the launching trajectory and are drawn to allow the trajectory plane to be inclined as much as 2° to the equatorial plane and away from the observer. The expected trajectory discussed in ref. 1, and drawn to scale as Fig. 1 in ref. 4 has been assumed. The extent of the region from which additional radar or optical data may be obtained is indicated by these curves. At their maximum breadth, the curves indicate the approximate limits within which it will be possible for suitable radars to observe an equatorial satellite on a circular orbit at a height of 350 miles. If the satellite should be at a greater height, the limits are extended; and conversely they are reduced if the satellite is at a lower height.

In the following discussion of a selection of individual site possibilities, it is well to refer to Fig. 5 and the maps of refs. 17 through 20. The material is somewhat abbreviated, but the meaning will be clear. The sites are taken in order eastward around the equator beginning with the South American region.

<u>Site 1:</u> (Ref. 17 for map details)

- L Coast of Ecuador near town of Manta
- H_1 Central Ecuador southeast of Mt. Cotopaxi near village of Napo
- B_1 Southern Colombia between Rio Putumayo and Rio Caquetá near village of La Chorrera
- B_2 City of Manãos, Brazil, or point 100 to 150 miles northwest along Rio Negro
- H_2 Coastal town of São Luiz do Maranhão, Brazil or any suitable coastal site up to 150 miles eastward

Comments: Launching site is about 90 miles south of the equator. Site of H_1 is difficult of access and unfortunately close to mountains.

Site of B_1 is very inaccessible. B_2 is at or near large accessible Amazon port, and H_2 is on the coast. A launching from these sites occupies the entire equatorial width of the continent of South America. Details are plotted in Fig. 5.

<u>Site 2:</u> (Ref. 17 for map details)

- L Northwestern Brazil near the village of São Gabriel where the Rio Negro crosses equator
- H_1 Near village of Calamaque on Rio Negro, Brazil
- B_1 Equator about 150 miles east of Rio Branco, Brazil
- B_2 City of Belém, Brazil or eastern end of Marajó Island at mouth of Amazon, Brazil
- H_2 St. Paul Rocks, Atlantic Ocean - owned by Brazil

Comments: L and H_1 are accessible by ship; they are located far in the interior of the Amazon system. B_1 is very inaccessible. H_2 is a very small site, but can be used if sea-birds do not cause too much trouble. The principal virtue of this set of sites is that it is entirely in the territory of a single country, Brazil.

<u>Site 3:</u> (Ref. 18 for map details)

- L São Tomé Island in the Gulf of Guinea - owned by Portugal
- H_1 Coast of French Equatorial Africa near town of Libreville
- B_1 Interior of French Equatorial Africa near the road junction village of Odzala
- B_2 Belgian Congo about 70 miles east of Stanleyville near the village of Bafwoboli on road eastward from Stanleyville
- H_2 City of Mogadiscio, Somaliland, or point up to 100 miles to the southwest along the coast.

Comments: B_1 and B_2 are moderately inaccessible. L, H_1, and H_2 are all quite accessible from the sea. Details are plotted in Fig. 5.

<u>Site 4:</u> (Ref. 18 for map details)

- L Coast of Rio Muni about 20 miles south of village of Bata - owned by Spain
- H_1 Interior of French Equatorial Africa, few miles east of Mt. Tembo
- B_1 French Equatorial Africa about 50 miles west of the Ubangi river
- B_2 Town of Entebbe, Uganda, or any convenient location in the area enclosed by Lakes Victoria, Albert, Edward, and Kyoga in Uganda
- H_2 Coast of Somaliland between Itala and Mogadiscio

Comments: Launching site is about 120 miles north of the equator. H_1 and B_1 are quite inaccessible. L and H_2 are accessible by sea.

Site 5: (Ref. 18 for map details)

- L Near village of Musoma on eastern (Tanganyika) shore of Lake Victoria in Central Africa.
- H_1 Near village of Ngong about 20 miles southwest of city of Nairobi, Kenya
- B_1 Northern end of Kenya coast, few miles north of village of Lamu
- B_2 Northernmost islands of Seychelles - Denis or Bird Island
- H_2 Suvadiva Atoll, Indian Ocean

Comments: Launching site is about 100 miles south of the equator. All sites are fairly accessible, but B_2 is somewhat too far south. All territory involved is under control of a single government, Great Britain.

Site 6: (Ref. 19 for map details)

- L Southern half of Nias Island off the west coast of Sumatra, Netherlands East Indies
- H_1 Village of Pasirpengarajan in interior of Sumatra
- B_1 Bintan Island of Riouw Archipelago about 100 miles southeast of Singapore
- B_2 Village of Kelolokan on the east coast of Borneo
- H_2 Biak Island or St. David Islands north of Dutch New Guinea

Comments: Launching site is about 80 miles north of the equator. H_1 is probably somewhat difficult of access. Both L and H_1 are in regions of rather unfavorable climate at nearly all seasons of the year. Trajectory passes rather close to Singapore. All territory involved is under control of the Netherlands.

Site 7: (Ref. 19 for map details)

- L Near village of Natal on the west coast of Sumatra
- H_1 About 80 miles up Kampar River, eastern Sumatra
- B_1 Badas Islands between Sumatra and Borneo
- B_2 Village of Sabang, Celebes
- H_2 Biak Island, or coast of Dutch New Guinea near mouth of Mamberamo River at Cape D'Urville.

Comments: All sites are reasonably accessible, but climatic difficulties are likely in Sumatra. Trajectory passes rather close to Singapore. All territory involved is under control of the Netherlands.

Site 8: (Ref. 19 for map details)

- L Lingga Island off the east coast of Sumatra
- H_1 Pedjantan Island between Sumatra and Borneo

B_1 150 to 200 miles up the Kapoeas River and inland from Pontianak, Western Borneo
B_2 Village of Gorontalo, Celebes, or coastal site a few miles east
H_2 Wuvulu Island off north coast of Australian Mandated New Guinea

Comments: Launching site is rather close to Singapore.

<u>Site 9:</u> (Ref. 19 for map details)

L Western Borneo about 15 miles south of Pontianak
H_1 Interior of Borneo near the village of Nangamaoe
B_1 Near village of Batakan, about 60 miles inland from Samarinda on eastern coast of Borneo
B_2 Gebe Island, Waigeo Island, or extreme northwest coast of Dutch New Guinea
H_2 Manus or Los Negros Island in the Admiralty Group

Comments: H_1 is in very rough and inaccessible country.

<u>Site 10:</u> (Ref. 19 for map details)

L Eastern Borneo coast about 40 miles north of Samarinda
H_1 West coast of Celebes about 20 miles south of village of Sabang
B_1 Coast of Celebes about 100 miles east of village of Gorontalo
B_2 Eastern end of Biak Island
H_2 Kapingamarangi Atoll south of the Carolines

Comments: All sites are fairly accessible and climatic conditions are fairly favorable. H_2 is at present under United States control; the rest of the sites are under control of the Netherlands.

<u>Site 11:</u> (Ref. 19 for map details)

L Near the village of Tinombo at western end of Gulf of Tomini, Celebes
H_1 Coast of Celebes near the village of Gorontalo
B_1 Near the village of Weda, Halmahera Island
B_2 Ninigo Group northwest of Admiralty Group
H_2 No suitable land, would have to use ship or Kapingamarangi Atoll south of the Carolines.

Comments: Lack of a suitable island for H_2 spoils this otherwise excellent launching site. The shores of the Gulf of Tomini, Celebes, offer unparalleled observation positions for early part of launching trajectory.

Site 12: (Refs. 19 and 20 for map details)

- L Halmahera Island about 30 miles south of village of Weda
- H_1 Waigeo Islands off northwest coast of New Guinea
- B_1 Northwestern tip of Biak Island
- B_2 Mussau Island, St. Matthias Group
- H_2 Nauru Island

Comments: Launching site is about 15 miles south of the equator. All sites are easily accessible and situated close to ideal positions. Climatic factors are reasonably favorable at all locations. Territory involved is Dutch (L, H_1, and B_1), Australian (B_2), and British (H_2). Details are plotted in Fig. 5.

Site 13: (Ref. 20 for map details)

- L Nauru Island
- H_1 Ocean Island
- B_1 Nonouti Island in the Gilbert Group
- B_2 Canton Island in the Phoenix Group
- H_2 No suitable land, would have to use ship or Christmas Island.

Comments: Launching site is about 35 miles south of the equator. Nauru Island is the only Pacific island launching site (excluding the Netherlands East Indies) possible, and because of the necessity for using Christmas Island for H_2, a site somewhat outside the tolerances established, Nauru is not really to be recommended. Nauru and Ocean Islands are British. Canton and Christmas Islands are claimed formally by Great Britain, but the United States, which has military installations on both, informally disputes the British title.

In addition to the above thirteen sites, the use of the Galápagos Islands has been suggested. Unfortunately it is not possible to find suitable land for the observing stations, but by locating L as far to the west in the islands as possible, say on Narborough Island, and by placing H_1 as far east as possible, say on Chatham Island, the observing can be accomplished although with neither greatest convenience nor accuracy. B_1 would have to be ship-borne between the islands and the South American mainland. B_2 would be in a very inaccessible region of eastern Colombia, and H_2 would be in the Brazilian jungle between the Amazon River and French Guiana.

VI. CONCLUSIONS

Conclusions as to the best possible equatorial launching site for the first experimental satellite rocket depend to a considerable extent on how strictly it ultimately will be necessary to adhere to the requirements stated in Section III. As there is no combination of possible launching site and ancillary observing sites which is entirely under the control of the United States, a launching will have to involve foreign governments. The region of the equatorial zone which seems to offer the best selection of possible launching sites is the Netherlands East Indies.

The following is a summary of the more detailed conclusions which can be arrived at as a result of the foregoing discussion:

1. The best overall launching site is on Halmahera Island in the Moluccas (Site 12), but a site on the eastern coast of Borneo is a very close contender (Site 10).

2. The best site in the South American region is a point on the coast of Ecuador near the town of Manta (Site 1).

3. The best site in the African region is on São Tomé Island in the Gulf of Guinea (Site 3); a site on the Tanganyika shore of Lake Victoria in central Africa is a close contender (Site 5).

4. From a security point of view, military as well as personal, a site in a fairly remote ocean region is desirable; the only possible site of this kind is Nauru Island in the Southwestern Pacific (Site 13).

5. The most favorable months in the year for the launching operation are July and August; January and February will also be moderately suitable at several possible sites.

6. The most favorable hours of the day for the launching operation, at any launching site, are from 0900 to 1200 local time.

7. The actual date and time of launching should be determined at the last possible moment, and should be based upon knowledge of the prevailing meteorological situation.

8. As a guiding principle it can be stated that the five sites required for a complete launching operation should involve the territory of a minimum number of foreign countries - preferably only one. Sites 2 (Brazil), 5 (Great Britain), 6 (Netherlands), 7 (Netherlands), 10 (Netherlands), and 13 (Great Britain) fulfill this requirement. Site 3 is the poorest from this point of view.

As a final word it is necessary to stress the point that the particular sites discussed in Section V have been selected in accordance with the planned launching trajectory[1] and the proposed observation and tracking system[4]. Should these plans undergo modification at some later time, it will be necessary to re-examine the equatorial zone to see which of the above sites are still useful, and to determine new possibilities. In general any increase in the length of the launching trajectory, or increase in the number of observing stations required for launching, will further restrict the number of possible sites.

APPENDIX

WEATHER IN THE DOLDRUM BELT OF THE ATLANTIC OCEAN

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APPENDIX

WEATHER IN THE DOLDRUM BELT OF THE ATLANTIC OCEAN*

PART I.

A. Introduction

From the early days of steam to the present war the passage of the Doldrums seldom called for special notice. Most shipping lines operating across the equator cut the belt at a fairly sharp angle which meant that, at worst, their vessels might experience fifty miles or so of heavy rainstorms and squally winds, with perhaps another hundred miles of light, variable winds and calms, with scattered showers, on either side; at best they might encounter only a few showers in the very heart of the belt. True, aircraft did occasionally report exceptionally tempestuous weather in low latitudes, but mostly they contrived to avoid it by keeping their trans-ocean schedules to the hours of daylight.

Since 1939 the position has become very different. Enemy raiders and U-boats operating in equatorial regions are known to use the cloud cover of the Doldrums (as an insurance against detection by reconnaissance planes) when refuelling or not actually 'hunting'. In the Indian Ocean the Japanese aircraft carrier responsible for the attack on Colombo was able to elude its pursuers by running for the same cover. (The Prime Minister's speech in the House following the announcement of the attack contained a most significant reference to the role played by bad weather on this occasion). In the Atlantic during the past winter several aircraft being ferried from S. America to W. Africa were lost, largely, so it would seem, because they were inadequately informed on the run of the Doldrum belt at that season and the very bad flying conditions that obtain along most of its length.

B. The Doldrums Defined

The Doldrums we take to be that part of the ocean lying in the shallow trough of low pressure permanently located between the Trade winds of the two hemispheres, where the characteristic features are calms and light variable winds accompanied by heavy rains, thunderstorms and violent squalls. Generally the winds and weather present a most marked contrast with the steady Trades.

C. Migration of the Doldrums

In the march of the seasons the Doldrum belt follows the sun, but with a pronounced time-lag, for it does not reach its extreme northern position until the end of August or the beginning of September, and its extreme southern position until the end of February or early March. In this respect the migration of the Doldrums is

* This appendix is a verbatim copy of Memorandum No. H.M.109/42 prepared by the Naval Meteorological Branch of the Royal Navy. It was obtained during the war and bore original classification equivalent to United States 'Restricted'. It has not been formally published elsewhere, so far as is known, and is reproduced here as a matter of convenience.

closely paralleled by the migration of the thermal equator (= maximum sea temperature): indeed in the open ocean at any given time there is likely to be less than ten to twenty miles difference between the centre of the belt and the thermal equator.

The mean position about which the belt oscillates does not lie on the equator but 4° - 5° N. It does not penetrate any distance south of the equator, except in the Gulf of Guinea and then only for three or four months (December-March). For the greater part of the year the axis of the Doldrum belt is orientated ENE-WSW: thus at the end of August it lies approximately 15° N off W. Africa (C. Verde Is.), but only 10° N off the S. American continent.

In addition to the seasonal movement of the Belt - the speed of which varies with the time of the year, being greatest round about April to August and October to December (when movements of 25 to 50 miles per day are not uncommon) - there are short period oscillations of 1° to 4° in as many days (see below).

D. Width of the Doldrums

If, for the sake of measurement, we take the belt as comprising only those areas where rainfall is reported on more than 25 - 30% of all occasions, then we find

(1) that it is almost always broader off the W. African than off the S. American coast;

(2) that it is narrowest in March and broadest in August: off W. Africa the mean widths are 150 miles and 500 miles respectively;

(3) that there are very considerable day-to-day variations: for weeks on end the belt is wide - up to 600 miles in some cases. Then comes a sudden burst of Trade winds invading the area and reducing the width of the belt between the opposing winds to almost nothing. After a while the Doldrums return to their normal width.

E. Variation of Weather

i. General

The most characteristic feature of Doldrum weather is the occurrence of violent, if short-lived squalls. (The word is used here in the sense in which it is ordinarily understood by seamen - not in its strict meteorological sense). Hardly ever does a ship's log fail to draw attention to them. They are first described as gigantic cumulo-nimbus clouds from the base of which torrential rain falls. Although they have been known to move in every direction, the majority travel from an easterly to a westerly point; lightning, poor visibility (often down to 500 yards), low cloud and steep seas are usual concomitants. In these squalls both wind and rain are not always present: some are rain-less, some wind-less. In wind-squalls, the force is very variable: force 8-9 has been reported on rare occasions, but 4-5 is much more usual. They differ essentially from the line-squall of extra-tropical regions in that the cloud, as seen from the distance, is more like a snow-clad mountain peak than a horizontal revolving cylinder.

And yet, in spite of the regularity with which these squalls are reported, the thing that stands out most in ships' logs and eye-witness accounts is that Doldrum weather is scarcely ever the same twice. In the W. African sector "the weather is usually fine for a short period, then deteriorates for a few days, constantly changing" (Met. Officer, Freetown). H.M.S. Formidable reports that on a given day the "belt of bad weather was not very bad". H.M.S. Devonshire operating in the same area only three weeks later reported the bad weather belt to be approximately 100 miles across, with heavy rain squalls (force 5 - 6) and water-spouts. H.M.S. Pretoria Castle operating about 40° W in the general vicinity of the Doldrums saw no sign of bad weather on one occasion, and only met with showery weather on three others. Other vessels commonly report that although the sky looks threatening and atmospherics are very troublesome, neither rain nor squalls materialise during their passage of the belt.

ii. Geographical

As far as the Atlantic Doldrum belt is concerned, there is ample evidence to show that the weather, by and large, is worst within 200 - 300 miles of the African coast and that it improves westwards of 40° - 45° W, by which time the rainfall frequency is not much higher in the Doldrum belt than on either side of it. But this is far from alleging, as some have done, that the bad weather belt peters out off the American coast. On the contrary it is very much in evidence in the West Indian region in summer (and is almost certainly the 'channel' by which hurricanes reach the Caribbean). At the same time it is no longer a clear-cut zone so many miles wide. For one thing the NE and SE Trades have had, by the time they reach the Caribbean, almost equally long trajectories over warm sea and are therefore more homogeneous - and more stable - than when they first impinged off the African coast. For another thing, the proximity of the mainland of the N. American continent means that air masses of very different history and properties 'feed' the equatorial low pressure belt and introduce non-periodic frontal elements which considerably complicate the Doldrum régime.

iii. Seasonal

Rainfall frequency figures reveal that, taking the belt as a whole, the maximum frequency occurs in August (50% approximately along the centre of the belt) and the minimum in February (30% frequency). That is, the worst weather (other things being equal, the higher the rain frequency the higher the frequency of squalls, low cloud and poor visibility) occurs when the belt is widest. and the best when it is narrowest.

RAINFALL FREQUENCY IN MID-DOLDRUMS

(250/30)	January	40%		July	48%
	February	32	(500)	August	50
(120/180)	March	35		September	40
(350)	April	46	(350)	October	38
(250)	May	43	(500)	November	48
	June	43		December	36

(The figures in brackets give the approximate width in miles of the 25-30% rainfall frequency zone).

iv. Diurnal

As comparatively few ships take as many observations during the night as during the day, the assessment of diurnal variation is not always easy. At first sight perhaps it is difficult to see why there is any such variation: since the mean variation of air temperature (in this region) is only 1.5° - 2.0°F and the variation of sea temperature only about 33% of this, we might well argue that there should be very little variation in the other elements. And it certainly is the case as far as rainfall *occurrence* goes. However, when we come to consider rainfall *amount*, we find that there is a most conspicuous variation, with a maximum round about 0600 and minimum round about mid-day. Wind velocity shows a somewhat similar variation: maximum c. 0300, minimum c. 1400. As for cloud amount, the variation is not quite so decided, but S.S. Meteor observations clearly show the amount to be lower by day than by night.*

Although strict comparison is not at present possible, such aircraft reports as are available leave us in no doubt about the badness of *night*-time conditions in the Doldrums. The following reports come from American pilots ferrying planes by night from S. America to W. Africa during the past January and February:-

a. "Continuous thunderstorms, icing conditions about 14,000 feet..."

b. "Slight snow two-thirds of the way over at 13,000 feet... very bad after first 900 miles. Heavy rain and icing at 18,000 feet. Cumulus and stratocumulus up to 22,000 feet..."

c. "Constant hail; cumulonimbus up to 20,000 feet..."

d. "Heavy rain and thunderstorms at heights from 6,000 to 15,000 feet".

N.B. It is worthy of note that these reports were made at a time of the year when surface conditions are least troublesome.

F. Mechanism of Doldrum Weather

i. The Rôle of Convection

According to the 'classical' explanation, the high sea temperatures of the equatorial zone heat the air, causing it to expand and rise. This leads to a poleward drift of air aloft and, at the surface, to a compensating convergence of air equatorwards (represented by the Trades) to feed the low pressure belt thereby created. The energy needed for this convectional process, once it has been started, is provided by the condensation which releases enough latent heat to extend the convection up to great heights.

Nor does there seem to be much wrong with this view, as very few Doldrum features cannot be explained by it. All the squall phenomena - even the diurnal variation of such phenomena - find their counterparts in the heat (or instability) thunderstorm experienced over tropical lands. The diurnal variation of rainfall, with its well-marked nocturnal maximum, emphasises how critical are the lapse rates over the sea in the Doldrums and how even the small diurnal variation of temperature increases the instability of the air column by night and diminishes it by day. Thus, by night, radiation of heat from cloud particles lowers the temperature at the top of the cloud more rapidly than at the bottom, 10 to 20,000 ft. below, where the sea exercises a

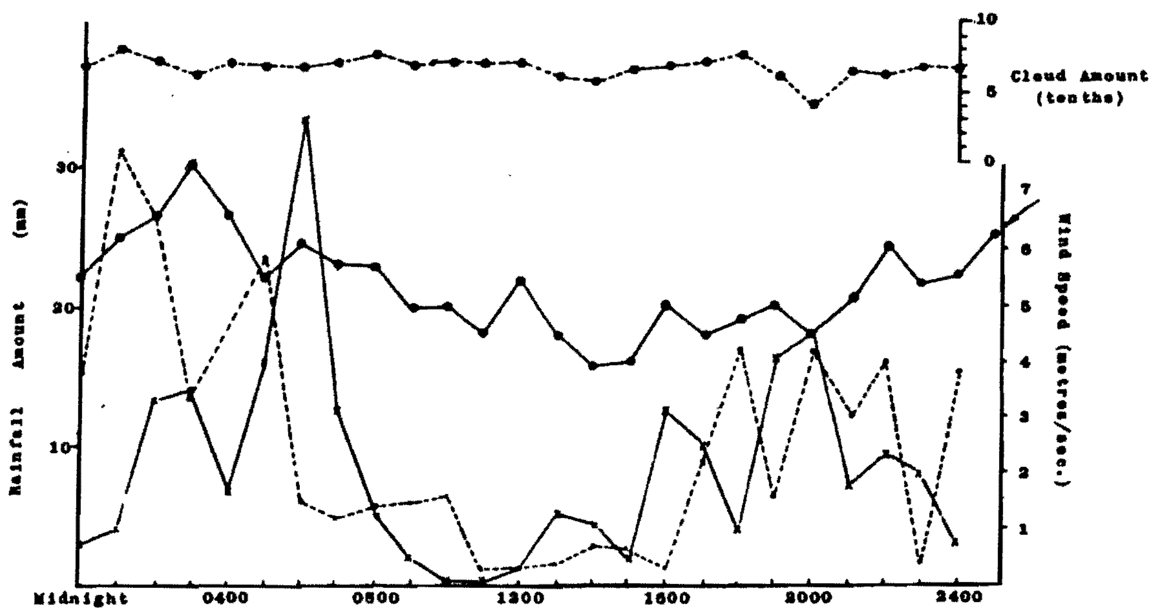
* See Diagram No. 1 at end of memorandum.

stabilising influence on temperature. Within the cloud a steeper (and unstable) lapse rate thus arises; this leads to a greater upward flow of water vapour and hence to greater precipitation.

This diurnal effect is probably most noticeable in summer in the Caribbean sector of the belt, because the sea temperature gradient here is almost negligible and the NE and SE Trades move along the isotherms rather than across them.

In passing, it is interesting to see that the striking diurnal variation of rainfall amount in the Doldrums is duplicated in all essentials in the Trades (see diagram No. 1) a fact to be borne in mind when arguing the case for the frontal origin of Doldrum weather.

DIAGRAM NO. 1



DIURNAL VARIATION OF WEATHER INTER-TROPICAL REGION

x———x *Rainfall amount in Doldrum Belt.* } Aggregates based on S.S. "Meteor."
--------- *Rainfall amount in Trade Wind Belt* }
•———• *Wind Speed in Doldrum Belt* } S.S. "Meteor" average.
•———• *Cloud Amount in Doldrum Belt* }

ii. Inter-tropical Fronts

The convergence of Trade winds from different hemispheres in the Doldrums provides, vide Petterssen, an excellent kinematic setting for frontogenesis, but the converging air-masses are too nearly alike to produce, other than in rare circumstances, fronts on the extra-tropical pattern. On the average there is not more than 1° - 2°F between the temperatures of the NE and S.E. Trades and SW Monsoon at any given level. The difference in the density of the air-masses involved is likewise very small. Now in the absence of distinct density differences it is physically impossible for a long, low-gradient front (e.g. of the warm front type) to exist. (It should be noted in this connection that the characteristic warm front cloud-sequence - cirrus, cirro-stratus, alto-stratus, stratus, etc. - is hardly ever observed in the tropics).

The 'rare circumstances' arise, according to Petterssen and others, when there is an active outbreak of polar air in the winter hemisphere. Then relatively cold air may be brought into juxta-position with equatorial air along the zone of convergence. In such cases, it is argued, fronts of appreciable intensity may form in the Doldrums; the strongest will be found when the temperature difference between the two hemispheres is greatest, which Petterssen asserts, is late summer and late winter, adducing the fact that it is at these seasons that tropical cyclones obtain their maximum frequency and intensity.

As far as the Atlantic belt is concerned, this argument is not entirely satisfactory. Admittedly the Atlantic is peculiar in keeping its Doldrum belt north of the equator (with the exceptions previously mentioned) - a fact which no doubt helps to explain why the bad weather belt is *not* at its worst in late winter. The chief objection to the argument is that the temperature difference between the two hemispheres, distance for distance on either side of the Doldrum belt, is *least* when the width and intensity of the bad weather zone is *greatest*, and conversely. The following table expresses this fact in a rather different form, but one that makes it quite clear that the incidence of maximum and minimum intensity of Doldrum weather cannot be correlated with temperature difference.

APPROXIMATE WIDTH OF OCEAN ON EITHER SIDE OF DOLDRUMS

WITH MEAN TEMPERATURE OF 68°F OR MORE

(in miles)

(Compare with Table on page 25).

Month	NE side	SE side	Total Width
January	1300	2500	3800
1 February	1200	2600	3800
March	1225	2500	3725
April	1250	2450	3700
May	1400	2400	3800
June	1750	2300	4050
July	2200	2275	4475
2 August	2300	2250	4550
September	2100	2200	4300
October	2000	2050	4050
November	1750	2150	3900
December	1500	2350	3850

1. Month of lowest rain frequency in Doldrums (see p. 25)
2. Month of highest rain frequency in Doldrums (see p. 25)

Let us suppose that there is an invasion of 'ex-polar' air southwards along the eastern flank of the Azores High. What will happen? If the invasion is rapid it is only able to acquire warmth and moisture in the very lowest layers and, helped by the comparatively steep sea temperature gradient off the west coast of Africa (steepest, incidentally, in March when the rain belt is narrowest and least intense, and slackest in August when the rain belt is widest and most intense),* it quickly becomes unstable and begins to convect before it has really reached the mean position of the Doldrum belt. There is little likelihood of a quasi-stationary or stable front developing in such circumstances, because the vertical exchange of air consequent upon the instability will quickly produce an air-mass similar in energy and all measurable qualities to that of the Doldrums itself. If, on the other hand, the invasion is slow - more in the nature of a surge - the invading air will have time to pick up considerably more heat and moisture from the warm Atlantic below: by the time it reaches the Doldrums there will probably be little to choose between the adjacent air-masses *at the surface*. Only aloft will there be sufficient difference in moisture and, so, in density to produce anything in the nature of a front.

Since therefore, the constituent air-masses are generally so nearly alike at the surface, whence comes the source of energy for the cyclonic disturbances - the tornadoes, travelling 'lows' and hurricanes which develop in the Doldrum zone? Most writers agree that it must be looked for in the energy produced by the condensation of water vapour from the moist air, though whether this is sufficient to warm the air aloft enough to produce decided temperature differences - and so produce an 'upper front' - is still a moot point.** But it is significant that the Doldrum belt is widest and experiences its worst weather when the mean sea temperature of the North and South Atlantic (between 40° N and 40° S approx.) is greatest and when, probably for that reason, the mean water content of the NE and SE Trades/SW Monsoon is likewise greatest. (See Table at bottom of p.28).

All of which makes it difficult to attribute the seasonal variations of Doldrum weather to frontal causes.

The problem of the mechanism of cyclonic disturbances within the belt remains.

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*Sea Temperature Gradient NE and SE of Doldrum Belt
(Measured NE and SE, i.e. along path of Trades,
from point where Doldrums cross the meridian 25° W)

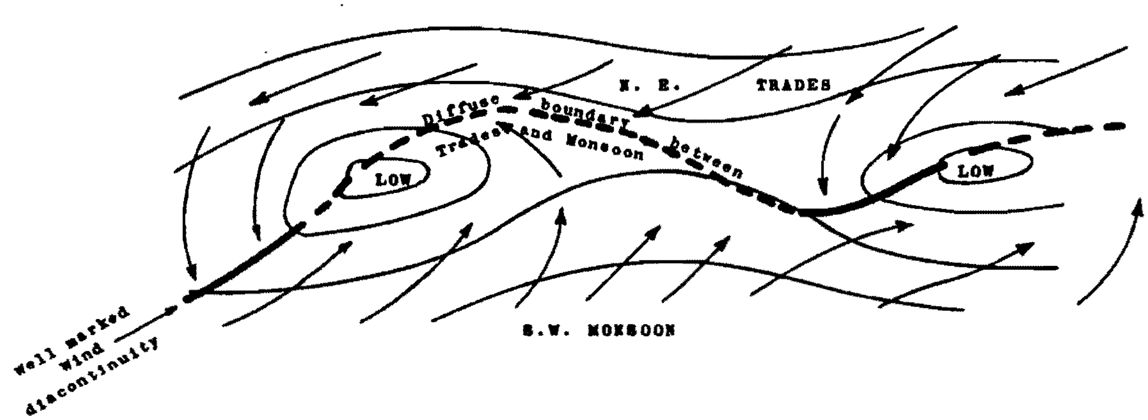
Month	NE of Doldrums	SE of Doldrums	
January	7°C per 1000 miles	2°C per 1000 miles	
February	7°C per 1000 miles	2°C per 1000 miles	
March	7.5°	+1.5°	Bad weather belt narrowest
April	7.0°	-1.5°	
May	5.5°	+1.5°	
June	4.5°	2.0°	
July	+3.5°	3.0°	
August	-3.5°	3.5°	Bad weather belt widest
September	4.0°	+3.0°	
October	4.5°	-3.0°	
November	5.0°	2.5°	
December	5.5°	2.0°	

**Even aloft (up to 10,000 ft. at least) it is extremely rare to find, in the Doldrum approaches, a difference of more than 3-4°F between the NE Trades and SE Trades (or SW Monsoon). As for vapour content, the corresponding difference is usually less than 2 grams per kilogram.

iii. Cyclonic Disturbances

In summer it appears that a quasi-stationary low over W. Africa throws off at irregular intervals shallow depressions which travel westwards. The air-masses involved in these 'lows' - the NE Trades and the SW Monsoon - encounter one another much as in Diagram 2. On the west side the Trade air-mass swings to the left and extends southwards as a NW wind encountering the monsoon air almost at right angles. On the east side the SW monsoon advances northward for a time, generally meeting the Trade at a more acute angle, but yields to the Trade as the next 'low' in the succession moves westward. The boundary between the two systems varies in consequence, sometimes as much as three or four degrees in a few days. How far over-and/or underthrusting occurs where the two masses meet it is difficult to say, but Meteor and H.M. ships' observations suggest that there is very little, if any at all. It is noteworthy (a) that 'lows' of this type can be traced as far as the Caribbean in summertime; (b) that they show an even distribution of frequencies on either side of the maximum period which is August-September. This is the season (i) when the Doldrum belt is in its most northerly position, (ii) when the W. African tornadoes (also farthest north at this season) are most vigorous and (iii) when the W. Indian hurricanes attain their maximum frequency. It seems not improbable, therefore, that the tornado and the hurricane (which upon occasion can be traced back as far as the C. Verde Isles) are particularly energetic disturbances - the hurricane much more so than the tornado - of the same type as the travelling 'low'.

DIAGRAM NO. 2



The primary condition necessary for the development of such low latitude disturbances - and according to many authorities the same condition is required for hurricanes and typhoons - is that there should be heavy convectional rain, due to the concerted uplifting of air over a considerable area. The longer the rain continues, the greater, apparently, is the chance of cyclonic development. This is because one effect of heavy precipitation over a relatively large region (where there is no rapid compensation of inflow) is to produce a slight decrease in pressure, resulting from loss of atmospheric mass and amounting to about 2 mb for each inch of rainfall. If the rains continue for several days in the same general region, the cumulative effect on pressure may be increased sufficiently to produce a shallow "Low". Provided the following three conditions are also satisfied, cyclonic activity may well be initiated in this way.

The conditions are:-

(1) The air-masses involved should be streaming away from the equator to a latitude where the Coriolis force of earth's rotation is enough to start spiraling of air around a centre; (at or near the equator vertical motion upward in moist, warm air is not enough to produce translational motion; the small squalls and thunderstorms resulting from the uplift are more or less static and simply serve to restore equilibrium to the atmosphere.)

(2) There must be a great depth of moist, potentially unstable air in at least one of the air-masses involved: (Deppermann, in treating of typhoons in the Philippines, says that the amount of heat liberated by condensation in the moist SW Monsoon is so much greater than that liberated by the drier NE Trade that the monsoon is able "to act aloft as a warm air-mass flanked by relatively cold air-mass" and so to derive the necessary energy for typhoon development.)

(3) The two air-masses should converge at a considerable angle.

These conditions are satisfied off the W. coast of Africa in summer, especially in August and September, when the Doldrum belt is farthest north.

G. Single Observer Aids to Forecasting Doldrum Weather

(1) Strength of the Trades.

If the rainfall of the Doldrums is predominantly convectional, we should expect to find some relation between the strength of the Trades feeding the convection currents and the amount of the rainfall. Investigation by Durst has shown that there is a striking relation between these two variables, frequent precipitation being associated with strong Trades, and conversely. (S.S. Meteor reported the heaviest rain in the Doldrums when the Trades were force 4-5, and lightest when they were force 1-2).

Ships approaching the Doldrums along the line of the Trades should therefore pay especial attention to the strength of the wind. As a rough rule, the Doldrums are likely to give their worst weather when the Trades are blowing more than force 4.

Variations in the strength of the Trades are significant for a further reason. When they blow unusually strong for a period, the warm layer of the surface water is driven forward and concentrated in the Equatorial current where it forms a plus departure in temperature. The place of the warm surface sheet is taken by cooler sub-surface water, making a minus departure. (N.B. The normal velocity of 9-10 m.p.h. - NE Trades - does not produce any marked disarrangement of the temperature gradient, but velocities in excess of 15 m.p.h. do). This means a tightening of the sea isotherms; this in turn means that strong Trades travelling over a surface with a minus departure will, on reaching Doldrum zone with its plus departure of temperature, be in a more unstable state than weak Trades which will effect no such concentration of warm surface waters, that is, they will cross a smaller number of sea isotherms during a given time or distance.

This 'unstabilising' effect is enhanced when the Trades blow strongly at the end of a spell of quiet, almost windless and sunny weather in the Doldrums. The sun will have caused a fairly marked increase in the sea surface temperature, leading to a slight steepening of the lapse rate in the lowest layers of the atmosphere. When such a situation synchronises with an invasion of cold air into the Trades, the subsequent indraught will make for strong convection and great squalliness and raininess. At the same time it should be noted that the increased surface wind stirring, consequent upon this increased convection, soon brings about a reduction of the sea surface temperature (of the order of 2°F), thereby decreasing the lapse rate and, with it, the intensity of the convection. (Tentative rule? 'The stronger the wind in the squall belt, the shorter the duration of bad weather at any given point').

(2) Air Temperature

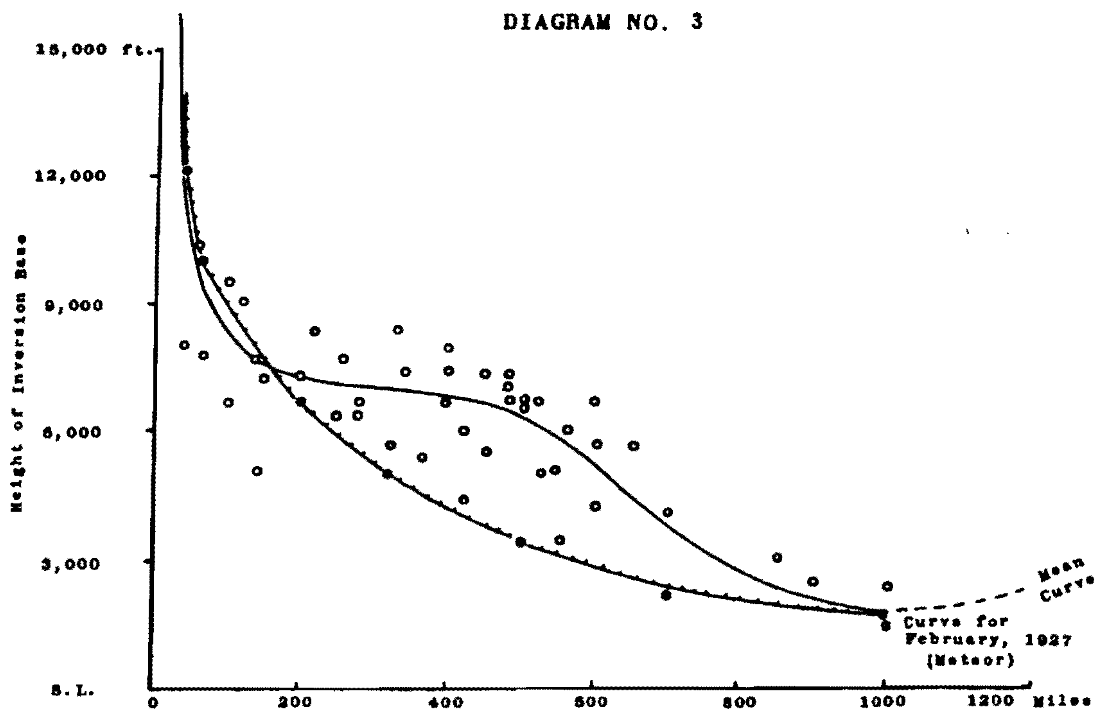
With above-average temperatures in the Trades and Doldrums, the rainfall is generally below the average - and conversely. On 13 occasions in 1923 when a 'warm period' could be distinguished the frequency of precipitation was computed (by Durst) in a strip of latitude 6° wide with its centre on the normal central line of the Doldrums. During two days before the maximum temperature was recorded, precipitation occurred on 35% of occasions: on the day of maximum temperature, on 48% of occasions and on 55% of occasions during the next two days, that is, when the temperature was falling. During 'cold periods', the reverse was found, the corresponding figures being 53%, 54% and 44%.

As the maximum precipitation zone coincides roughly with the zone of maximum instability, which can be equated with the zone of the thermal equator (see below), it is only to be expected that the lapse rate in the lowest layers of the atmosphere will have a lot to do with intensity of precipitation. The lower the air temperatures are, the steeper the lapse rate will be, and the greater the ease with which the convectional mechanism is set in motion. As a general rule we can take it that where, in the vicinity of the Doldrums, the surface air temperature is more than 2° - 3°F below the sea temperature, rain is probable, and extremely improbable where it is equal to, or above, the sea temperature.

(3) Upper Air Temperature

Observations from the S.S. Meteor indicate that lapse rates in the lower layers of the Trades are normally a good deal higher than is suggested by older figures, reaching 1°F per 165 feet below 650 feet, and 1°F per 190 feet from 650 to 3,300 feet in the heart of the Trades. Above 3,300 feet, even below that height sometimes, the Trade wind inversion makes average lapse rates meaningless; the increase of temperature at the inversion frequently being as much as 8°F in 300 feet. Consequently it is difficult to formulate any useful rules relating to variation of lapse rates with distance from the Doldrums. At the same time the upper air temperatures suggest that there may be a connection between the height of the base of the inversion and distance from the Doldrums. This is not altogether surprising when we remember (a) that the descent and compression of the air evacuated from the Doldrum zone by the counter-Trades increases in rate and amount with distance from the heat equator (attaining its maximum about 25° - 30° N and S,) (b) that the surface temperature of the cool air mass of the NE Trades steadily increases with approach to the Doldrums (by approximately 10°F as it passes from 30° N to 10° N), and (c) that there is a similar increase in the sea - air temperature difference, i.e. in the lapse rate of the bottom layers of the atmosphere. As this lapse rate increases, so does the rate of vertical exchange of air. This not only blocks the further descent of air carried northwards by the counter-Trades and so weakens the inversion, but increases the lapse rate immediately below the inversion level. In this way the inversion is gradually eliminated from below, the base of it being pushed progressively higher as the Doldrums are neared. Eventually, somewhere in the region of 150 miles from the mean centre of the Doldrum belt, the inversion lid is 'liquidated' altogether. At this point convection is no longer held in check; on the contrary it is definitely encouraged by the humidity contrast between the now very moist NE Trades and the drier air aloft. Aided by the ever-growing warmth of the sea surface - the thermal equator as we have already observed coincides approximately with the mean centre of the Doldrums - the overturning of the atmosphere is thus extended to high levels. The growing depth of the instability layer is indicated by the substitution of fair-weather cumulus, first by deeper, congested cumulus, and later by the towering anvils of cumulonimbus. Diagram No. 3 gives a first approximation to the mean variation of height of inversion base with distance - north and south - from the Doldrums. (N.B. There are considerable variations from time to time in the level at any given point, as is evident from the spread of the dots, but the variations from day to day do not seem to be considerable - *vide* graph for Meteor passage in February).

DIAGRAM NO. 3



GRAPH SHOWING VARIATION OF HEIGHT OF INVERSION BASE IN N.E. AND S.E. TRADES WITH DISTANCE FROM DOLDRUM BELT

(4) Sea Temperature

We have seen that, over the sea, heat thunderstorms, and the whole range of Doldrum weather may develop if cold air which is unstable aloft flows over warm water, the surface heating providing the necessary trigger action to set the convectional mechanism going. When the upper air temperatures on the Doldrum side of the Trade winds show that the inversion is about to be 'ironed out', then sea temperatures will give a most useful clue to the onset of Doldrum weather, for a very little increase of temperature at the surface level (such as air approaching the thermal equator will receive), will probably be quite enough to 'pull the trigger'. We say "very little" advisedly, because lapse rates verge on instability in the equatorial sectors of the Trade belt, except in the immediate region of the inversion. In other words, air coming up to the thermal equator (= max. *sea* temperature zone) in the Doldrums will behave in much the same way as air bordering on instability does when it crosses an island in the day time.*

(5) Clouds

As the Doldrums are approached the flattened, fair-weather cumulus clouds, typical of the Trades, grow in extent and depth. In the Trades proper the amount of low cloud may be 6-7/10 when the wind is strong, but usually it is not more than 5/10. When 100 to 150 miles from the heart of the bad weather belt - the distance depending apparently on the intensity of the convection**-altocumulus is frequently observed. Although it does not always appear to be present, its occurrence can be regarded as an almost certain sign of bad weather ahead. Nearer the belt, say 50 miles away, Acu gives way to Ast and the sky grows increasingly dark and threatening.

Within the Doldrums, rain-squalls and travelling 'Lows' are usually heralded by unbroken lines of Cunb - visible up to 100 miles off in exceptional circumstances - and attended by a 10/10 altostratus overcast. Cirriform clouds are more common in the belt than in the approaches.

The emissary types are roughly the same in the NE and SE Trades, and in the SW Monsoon, though occasionally the clouds are heavier and deeper in the SW Monsoon than in the NE Trades.

(6) Wind Direction

In spite of many opinions to the contrary, it is by no means generally true that "the first indication of a ship's approach to such a boundary (i.e. between the Trades, or between Trades and the Monsoon) is a marked change in wind direction at higher levels". Using the profiles based upon the numerous soundings (more than two-hundred)

* It is more than likely that the C. Verde Isles and W. African islands generally do much to 'feed' the instability which is required for the development of hurricanes, squalls, etc. If the islands are very small, as most of them are, the instability phenomena will probably not get into their stride until the ascending air has been carried some distance westwards by the wind - which may help to explain why so few hurricanes have been traced back as far as the African islands.

**The greater the convection within the Doldrums, the greater appears to be the marginal overflow of the air aloft and centrifugal scattering of the 'emissary' clouds. Unless it is a by-product of convection it is difficult to see how the ascent of water-vapour to the middle and high cloud levels is effected, for 'warm-front' lifting seems to be essentially an extra-tropical device.

made by the Meteor in the equatorial Atlantic it is evident that the NE Trades over-run the SE Trades in some places (and seasons), and that the SE Trades over-run the NE at others. If anything, there is a greater tendency for the SE Trades and SW Monsoon, because of their slightly greater warmth and moisture throughout most of the year, to over-run the NE Trades. When this happens there may be a wind shift on the northern side of the boundary (provided, of course, that convection is not sufficiently vigorous to destroy it), but it is hard to see how there can be one on the southern side.

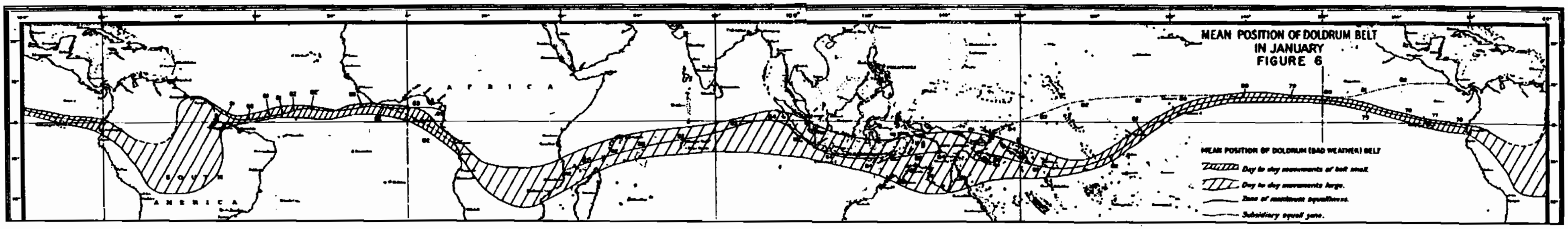
(7) Specific Humidity

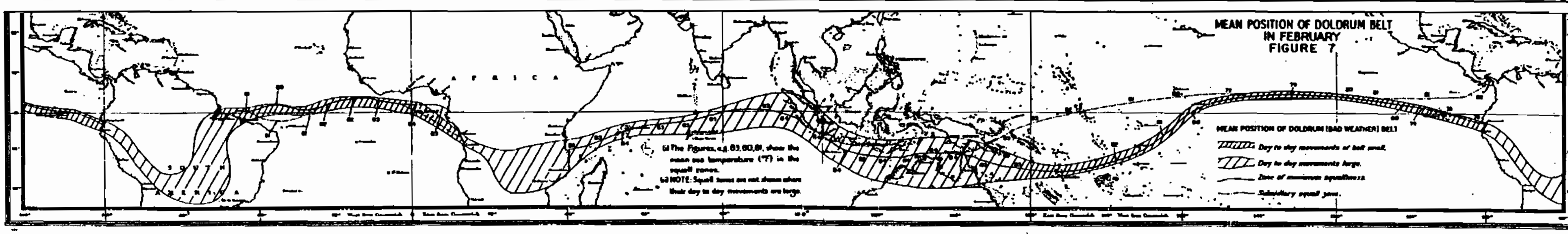
As a rough and ready guide (based on Meteor records) the risk of rain falling in the Doldrum belt is not great until the specific humidity has risen above 18 grams Kgrams.

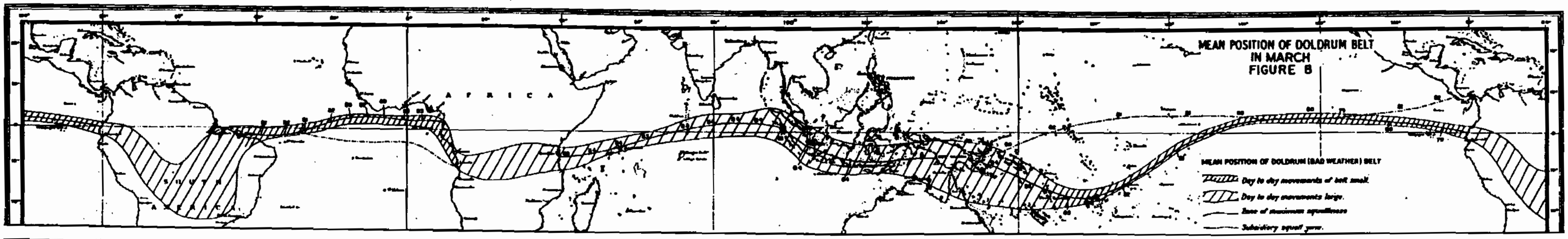
(8) Pressure (Synoptic, rather than single observer aids)

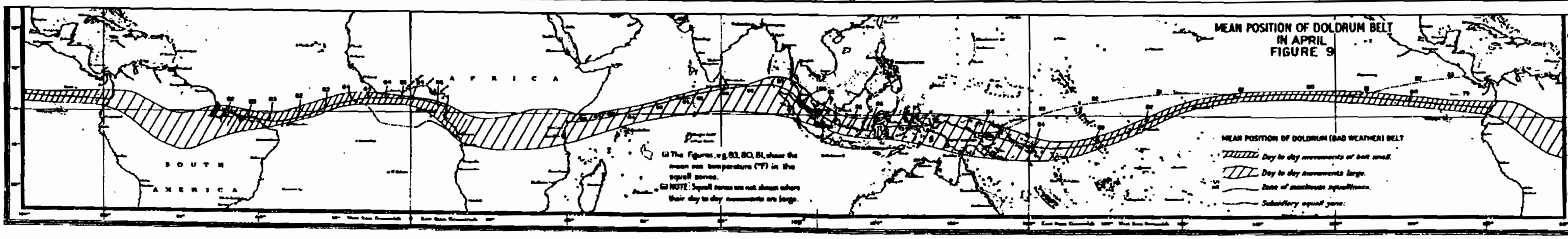
The general indication of the Doldrum zone is a shallow low pressure area, and pressure differences of 1 to 3 mbs over a range of 500 miles or so are quite significant in this respect. For this reason it is desirable to draw isobars for every millibar in the inter-tropical belt. Generally speaking the minimum pressure in the heart of the Doldrums does not fall below 1010 mbs except in revolving tropical storms, and does not rise above 1013 mbs (readings at midnight).

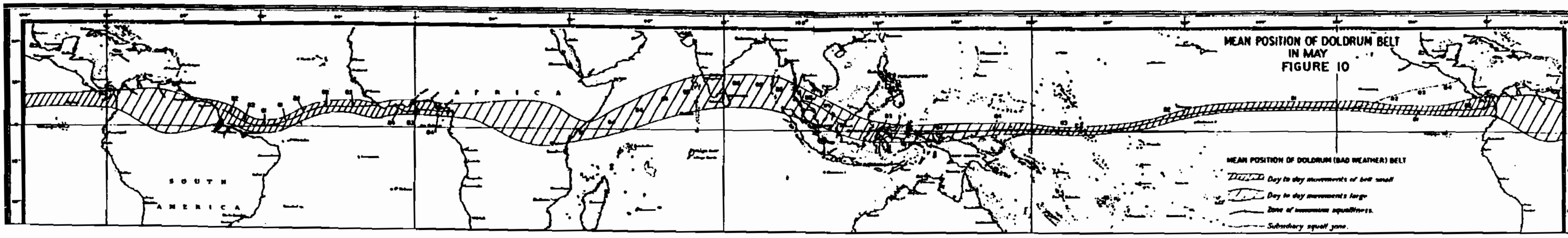
Examination of synoptic charts for the tropical W. Atlantic shows, more often than not, *vide* Dunn, a succession of waves of rising and falling pressure of slight intensity (of the order of 1 to 2 mbs) moving from east to west. Although sometimes months pass without their giving rise to any notable weather feature (notable, that is, as far as the Caribbean region is concerned) it is advisable to keep a fairly close watch on them as, given favourable upper air conditions (e.g. steep lapse rate) they are liable to develop into tropical storms.

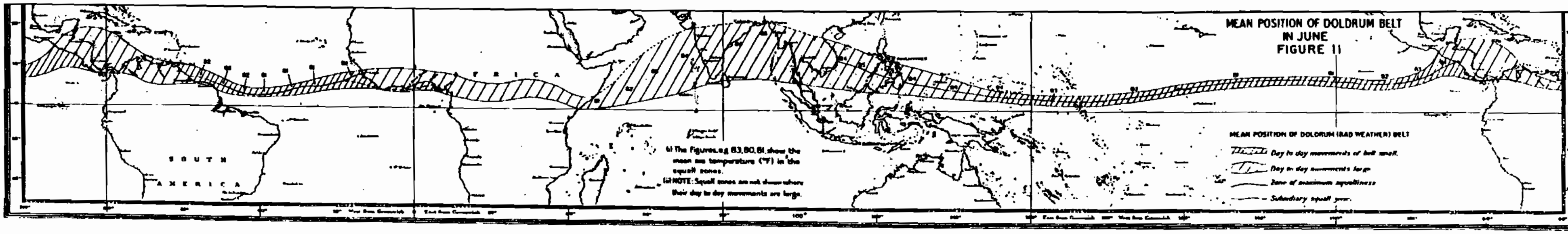

MEAN POSITION OF DOLDRUM BELT
IN JANUARY
FIGURE 6
AFRICA
SOUTH
AMERICA
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.

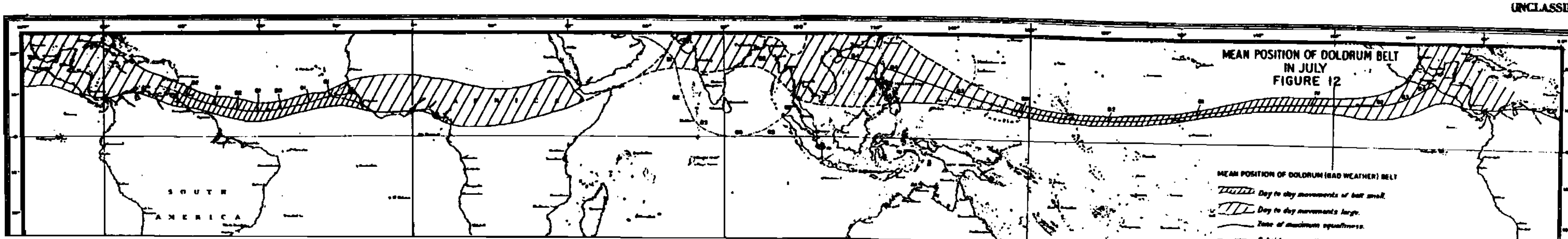

MEAN POSITION OF DOLDRUM BELT
IN FEBRUARY
FIGURE 7
AFRICA
SOUTH
AMERICA
(a) The Figures, e.g. 83, 80, 81, show the mean sea temperature (°F) in the squall zones.
(b) NOTE: Squall zones are not shown where their day to day movements are large.
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.

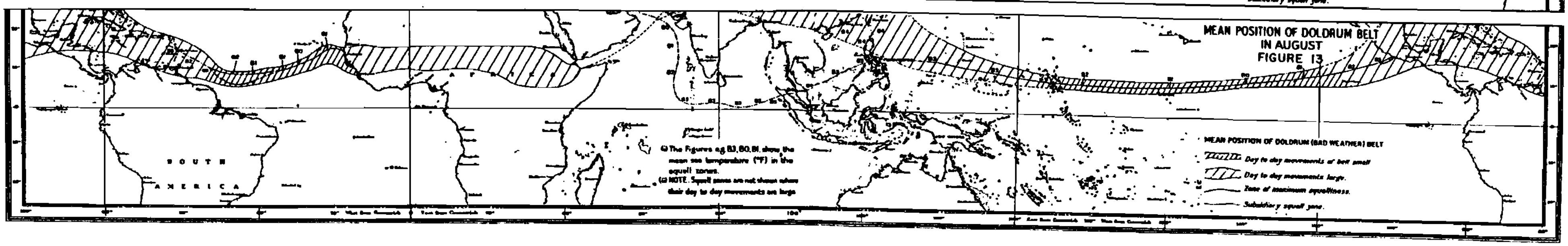

AFRICA
SOUTH AMERICA
MEAN POSITION OF DOLDRUM BELT
IN MARCH
FIGURE 8
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness
Subsidiary squall zone.

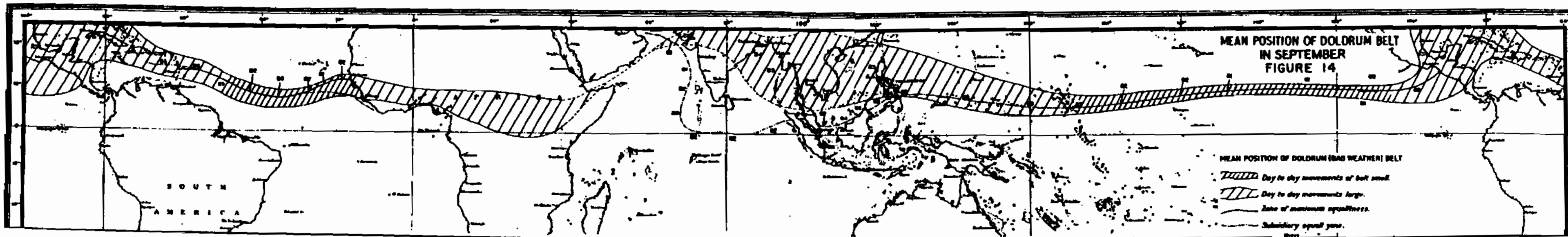

AFRICA
SOUTH AMERICA
MEAN POSITION OF DOLDRUM BELT
IN APRIL
FIGURE 9
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.
(1) The figures, e.g. 83, 80, 81, show the mean sea temperature (°F) in the squall zones.
(2) NOTE: Squall zones are not shown where their day to day movements are large.

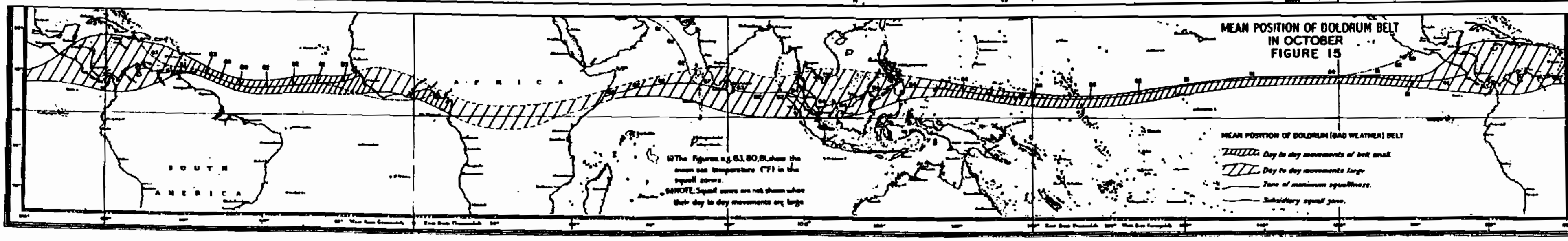

MEAN POSITION OF DOLDRUM BELT
IN MAY
FIGURE 10
SOUTH AMERICA
AFRICA
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small
Day to day movements large
Subsidiary squall zone.

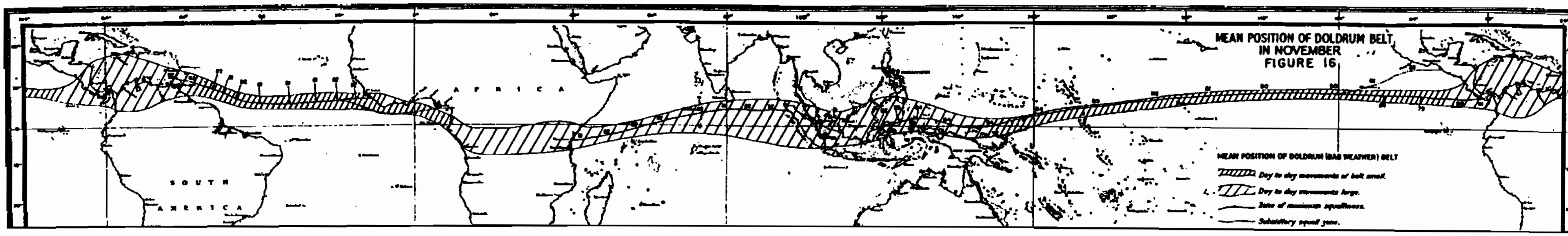

MEAN POSITION OF DOLDRUM BELT
IN JUNE
FIGURE 11
SOUTH AMERICA
(1) The figures, e.g. 83, 80, 81, show the mean sea temperature (°F) in the squall zones.
(2) NOTE: Squall zones are not drawn where their day to day movements are large.
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small
Day to day movements large
Subsidiary squall zone.
100°

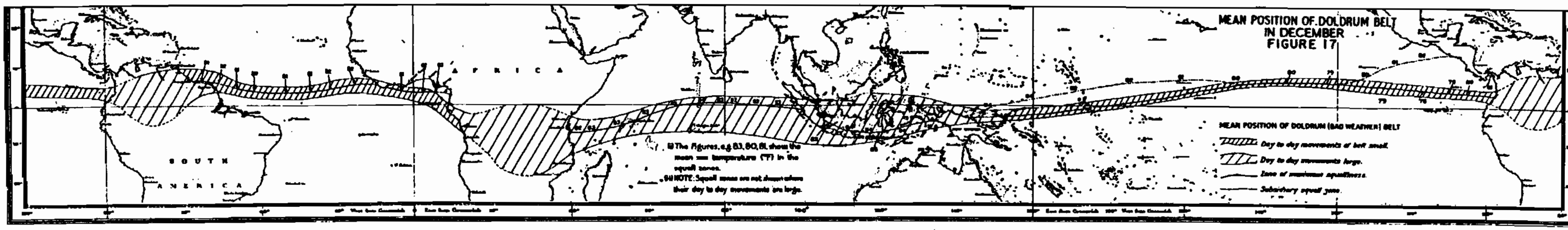

MEAN POSITION OF DOLDRUM BELT
IN JULY
FIGURE 12
SOUTH
AMERICA
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.


MEAN POSITION OF DOLDRUM BELT
IN AUGUST
FIGURE 13
SOUTH
AMERICA
(a) The Figures e.g. 83, 80, 81, show the mean sea temperature (°F) in the squall zones.
(b) NOTE. Squall zones are not shown where their day to day movements are large
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.


MEAN POSITION OF DOLDRUM BELT
IN SEPTEMBER
FIGURE 14
SOUTH
AMERICA
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.


MEAN POSITION OF DOLDRUM BELT
IN OCTOBER
FIGURE 15
AFRICA
SOUTH
AMERICA
(a) The Figures, e.g. 83, 80, 81, show the mean sea temperature (°F) in the squall zones.
(b) NOTE: Squall zones are not shown when their day to day movements are large
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.


MEAN POSITION OF DOLDRUM BELT
IN NOVEMBER
FIGURE 16
AFRICA
SOUTH
AMERICA
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.


MEAN POSITION OF DOLDRUM BELT
IN DECEMBER
FIGURE 17
AFRICA
SOUTH
AMERICA
(i) The Figures, e.g. 83, 80, 81, show the mean sea temperature (°F) in the squall zones.
(ii) NOTE: Squall zones are not drawn where their day to day movements are large.
MEAN POSITION OF DOLDRUM (BAD WEATHER) BELT
Day to day movements of belt small.
Day to day movements large.
Zone of maximum squalliness.
Subsidiary squall zone.

REFERENCES

[1] Krueger, R.W., Grimminger, G., and Tieman, E.M.: Flight Mechanics of a Satellite Rocket, RA-15021, Project RAND, Douglas Aircraft Company, Inc., Feb. 1, 1947.

[2] Frick, R.H.: Stability and Control of a Satellite Rocket, RA-15025, Project RAND, Douglas Aircraft Company, Inc., Feb. 1, 1947.

[3] Clement, G.H.: Structural and Weight Studies of a Satellite Rocket, RA-15026, Project RAND, Douglas Aircraft Company, Inc., Feb. 1, 1947.

[4] Bailey, D.K. and Mengel, A.S.: Communication and Observation Problems of a Satellite, RA-15028, Project RAND, Douglas Aircraft Company, Inc., Feb. 1, 1947.

[5] Lipp, J.E.: Cost Estimate of an Experimental Satellite Program, RA-15030, Project RAND, Douglas Aircraft Company, Inc., Feb. 1, 1947.

[6] —— Reference Papers Relating to a Satellite Study, RA-15032, Project RAND, Douglas Aircraft Company, Inc., Feb. 1,1947.

[7] —— Preliminary Design of an Experimental World-Circling Space Ship, SM-11827, Douglas Aircraft Company, Inc., May 2, 1946.

[8] —— Relative Sky-Wave Signal Strengths Required for Intelligible Reception of Various Types of Radio Communication Service, Technical Report No. 4, Radio Propagation Unit, Holabird Signal Depot, Baltimore, August 1945.

[9] —— Minimum Required Field Intensities for Intelligible Reception of Radio-telephony in Presence of Atmospherics or Receiving Set Noise, Technical Report No. 5, Radio Propagation Unit, Holabird Signal Depot, Baltimore, Dec. 1945.

[10] Schafer, J.P. and Goodall, W.M.: Peak Field Strength of Atmospherics Due to Local Thunderstorms at 150 Megacycles, Proc. I.R.E., Vol. 27, Mar. 1939.

[11] Shaw, Napier: Comparative Meteorology, Manual of Meteorology, Vol. II, University Press, Cambridge, 1928.

[12] Brooks, C.E.P.: The Distribution of Thunderstorms over the Globe, Geophysical Memoirs, No. 24, Air Ministry Meteorological Office, H.M.S.O., London, 1925.

[13] Haurwitz, B., and Austin, J.M.: Climatology, McGraw-Hill Book Company, Inc., New York, 1944.

[14] Jaeger, J.C.: Atmospherics and Noise Level, Report No. R.P. 184, Radio-physics Laboratory, Council for Scientific and Industrial Research, Sydney, July, 1943.

[15] —— Weather in the Doldrum Belt of the Atlantic Ocean, Memo. No. H.M. 109/42, Naval Meteorological Branch, Hydrographic Dept. Admiralty, London, June, 1942.

[16] —— Monthly Charts Showing Mean Position of Doldrum Belt, Supplement to Memo. No. H.M. 109/42, Naval Meteorological Branch, Hydorgraphic Dept. Admiralty, London, June, 1942.

[17] —— South America (Map), National Geographic Magazine, Washington, Oct. 1942.

[18] —— Africa (Map), National Geographic Magazine, Washington, Feb. 1943.

[19] —— Southeast Asia (Map), National Geographic Magazine, Washington, Oct. 1944.

[20] —— Pacific Ocean and the Bay of Bengal (Map), National Geographic Magazine, Washington, Sept. 1943.

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Northrop Aircraft Inc. Hawthorne, California		AAF
Princeton University Physics Department Princeton, New Jersey Attn: Dr. John A. Wheeler	Development Contract Officer Princeton University Princeton, New Jersey	BUORD

C. PRIME CONTRACTORS (Cont'd)

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Princeton University (3 copies) Princeton, New Jersey Attn: Project SQUID	Commanding Officer Branch Office Office of Naval Research 90 Church Street - Rm 1116 New York 7, New York	BUAER
Radio Corporation of America Victor Division Camden, New Jersey Attn: Mr. T. T. Eaton		AAF & BUORD
Radioplane Corporation Metropolitan Airport Van Nuys, California	Bureau of Aeronautics Rep. Lockheed Aircraft Corp. 3565 North Hollywood Way Burbank, California	BUAER
Raytheon Manufacturing Co. Waltham, Massachusetts Attn: Mrs. H. L. Thomas	Inspector of Naval Material Park Square Building Boston 16, Mass.	AAF & BUAER
Reeves Instrument Corp. 215 E. 91st Street New York 28, N.Y.	Inspector of Naval Material 90 Church St. New York 7, N.Y.	BUAER
Republic Aviation Corp. Military Contract Dept. Farmingdale, L.I., N.Y. Attn: Dr. William O'Donnell		AAF
Ryan Aeronautical Co. Lindberg Field San Diego 12, California Attn: Mr. B. T. Salmon		AAF
S. W. Marshall Co. Shoreham Building Washington, D. C.	Inspector of Naval Material 401 Water Street Baltimore 2, Maryland	BUAER
Sperry Gyroscope Co., Inc. Great Neck, L.I., N.Y.	Inspector of Naval Material 90 Church Street New York 7, N.Y.	BUAER ORD DEPT
United Aircraft Corp. Chance Vought Aircraft Div. Stratford, Conn. Attn: Mr. P. S. Baker	Bureau of Aeronautics Rep. United Aircraft Corp. Chance Vought Aircraft Div. Stratford 1, Conn.	BUAER
United Aircraft Corp. Research Department East Hartford, Conn. Attn: Mr. John G. Lee	Bureau of Aeronautics Rep. United Aircraft Corp. Pratt & Whitney Aircraft Div. East Hartford 8, Conn.	BUORD
University of Michigan Aeronautical Research Center Willow Run Airport Ypsilanti, Michigan Attn: Mr. R. F. May Dr. A. M. Kuethe		AAF
University of Southern California Naval Research Project, College of Engineering Los Angeles, California Attn: Dr. R. T. DeVault	Bureau of Aeronautics Rep. 15 South Raymond Street Pasadena, California	BUAER
University of Texas Defense Research Lab. Austin, Texas Attn: Dr. C. P. Boner	Development Contract Officer 500 East 24th Street Austin 12, Texas	BUORD
Willys-Overland Motors, Inc. Maywood, California Attn: Mr. Joe Talley	Representative-in-Charge, BUAER Consolidated-Vultee Aircraft Corp. Downey, California	BUAER

D. COMPONENT CONTRACTORS

(1) AERODYNAMICS & BALLISTICS

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
New Mexico School of Mines Research & Development Div. Albuquerque, New Mexico	Development Contract Officer New Mexico School of Mines Albuquerque, New Mexico	BUORD
New Mexico School of Agriculture & Mechanic Arts State College, New Mexico Attn: Dr. George Gardner	Development Contract Officer New Mexico School of Mines Albuquerque, New Mexico	BUORD
New York University Applied Mathematics Center New York, New York Attn: Mr. Richard Courant	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Office of the Chief of Ordnance Ordnance Research & Development Division Research & Materials Branch Ballistics Section Pentagon Washington 25, D.C.		ORD DEPT
Polytechnic Institute of Brooklyn Brooklyn, New York Attn: Mr. R.P. Harrington	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
University of Minnesota Minneapolis, Minnesota Attn: Dr. Akerman	Inspector of Naval Material Federal Bldg. Milwaukee 2, Wis.	BUORD
Aerojet Engineering Corp. Azusa, California Attn: K.F. Mundt	Bureau of Aeronautics Rep. 15 South Raymond Street Pasadena, California	BUAER
Marquardt Aircraft Co. Venice, California Attn: Dr. R. E. Marquardt	Bureau of Aeronautics Rep. 15 South Raymond Street Pasadena, California	BUAER

(2) GUIDANCE & CONTROL

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Belmont Radio Corporation 5921 West Dickens Avenue Chicago 39, Illinois Attn: Mr. Harold C. Mattes		AAF
Bendix Aviation Corp. Eclipse-Pioneer Division Teterboro, New Jersey Attn: Mr. R. C. Sylvander	Bureau of Aeronautics Resident Representative Bendix Aviation Corp. Teterboro, New Jersey	BUAER
Bendix Aviation Corp. Pacific Division, SPD West North Hollywood, Calif.	Development Contract Officer Bendix Aviation Corp. 11600 Sherman Way North Hollywood, California	BUORD
Bendix Aviation Radio Division East Joppa Road Baltimore 4, Maryland Attn: Mr. J. W. Hammond		AAF
Buehler and Company 1607 Howard Street Chicago 26, Illinois Attn: Mr. Jack M. Roehn		AAF
Commanding General Army Air Forces Pentagon Washington 25, D.C. Attn: AC/AS-4, DRE-2F		AAF

D. COMPONENT CONTRACTORS (Cont'd)

(2) GUIDANCE & CONTROL

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Consolidated-Vultee Aircraft Corporation San Diego, California Attn: Mr. C. J. Breitwieser	Bureau of Aeronautics Representative, Consolidated-Vultee Aircraft Corp. San Diego, California	BUAER
Cornell University Ithaca, New York Attn: Mr. William C. Ballard, Jr.		AAF
Director, U.S. Navy Electronics Laboratory, San Diego, California		NAVY
Electro-Mechanical Research Ridge Field, Connecticut Attn: Mr. Charles B. Aiken		AAF
Farnsworth Television and Radio Co. Fort Wayne, Indiana Attn: Mr. J. D. Schantz	DCO, Applied Physics Laboratory Johns Hopkins University 8621 Georgia Avenue, Silver Spring, Maryland	BUORD
Federal Telephone and Radio Corp. 200 Mt. Pleasant Avenue Newark 4, New Jersey Attn: Mr. E. N. Wendell		AAF
Galvin Manufacturing Corp. 4545 Augusta Blvd. Chicago 5, Illinois Attn: Mr. G. R. MacDonald		AAF
G. M. Giannini and Co., Inc. 285 West Colorado St. Pasadena, California	Bureau of Aeronautics Rep. 15 South Raymond St. Pasadena, California	BUAER
Gilfillan Corp. 1815-1849 Venice Blvd. Los Angeles 6, California Attn: Mr. G. R. Miles		AAF
Hillyer Engineering Co. New York, New York Attn: Mr. Curtiss Hillyer	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Kearfott Engineering Co. New York, New York Attn: Mr. W. A. Reichel	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Lear Incorporated 110 Iona Avenue, N.W. Grand Rapids 2, Michigan Attn: Mr. R.M. Mock		AAF
Manufacturers Machine & Tool Co. 320 Washington Street Mt. Vernon, N.Y. Attn: Mr. L. Kenneth Mayer, Comptroller		AAF
Minneapolis-Honeywell Mfgr. Co. 2753 Fourth Avenue Minneapolis 8, Minnesota Attn: Mr. W. J. McGoldrick, Vice-President		AAF
Ohio State University Research Foundation Columbus, Ohio Attn: Mr. Thomas E. Davis, Staff Assistant		AAF

D. COMPONENT CONTRACTORS (Cont'd)

(2) GUIDANCE & CONTROL

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Haller, Raymond & Brown P.O. Box 342 State College, Pennsylvania Attn: Dr. R. C. Raymond, Pres.		AAF
Office of Chief Signal Officer Engineering & Technical Services, Engineering Division Pentagon Washington 25, D.C.		ORD DEPT
Raytron, Inc. 209 E. Washington Avenue Jackson, Michigan Attn: Mr. John R. Gelzer, Vice-Pres.		AAF
L. N. Schwein Engineering Co. 5736 Washington Blvd. Los Angeles 16, California Attn: L.N. Schwein, General Partner		AAF
Senior Naval Liaison Officer U.S. Naval Electronic Liaison Office Signal Corps, Engineering Laboratory Fort Monmouth, New Jersey		NAVY
Servo Corporation of America Huntington, L.I., New York	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Square D Co. Kollsman Instrument Division Elmhurst, New York Attn: Mr. V. E. Carbonara	Bureau of Aeronautics Rep. 90 Church Street New York 7, New York	BUAER
Stromberg-Carlson Company Rochester, New York Attn: Mr. L.L. Spencer, Vice-Pres.		AAF
Submarine Signal Company Boston, Massachusetts Attn: Mr. Edgar Horton	Development Contract Officer Massachusetts Institute of Technology Cambridge 39, Massachusetts	BUORD
Summers Gyroscope Co. 1100 Colorado Avenue Santa Monica, California Attn: Mr. Tom Summers, Jr.		AAF
Sylvania Electric Products Inc. Flushing, Long Island, N.Y. Attn: Dr. Robert Bowie	Inspector of Naval Material 90 Church Street New York 7, New York	BUORD
University of Illinois Urbana, Illinois Attn: Mr. H. E. Cunningham, Sec.		AAF
University of Pennsylvania Moore School of Electrical Engr. Philadelphia, Pa.	Commanding Officer Naval Aircraft Modification Unit Johnsville, Pa.	BUAER
University of Pittsburgh Pittsburgh, Pennsylvania Attn: Mr. E. A. Holbrook, Dean		AAF
University of Virginia Physics Department Charlottesville, Virginia Attn: Dr. J. W. Beams	Development Contract Officer University of Virginia Charlottesville, Virginia	BUORD

D. COMPONENT CONTRACTORS (Cont'd)

(2) GUIDANCE & CONTROL

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Washington University Research Foundation 8135 Forsythe Blvd., Clayton 5, Missouri Attn: Dr. R. C. Spencer		AAF
Westinghouse Electric Corp. Springfield, Massachusetts Attn: J.K.B. Hare, Vice-Pres. (Dayton Office)		AAF
Director of Specialty Products Development Whippany Radio Laboratory Whippany, N.J. Attn: Mr. M.H. Cook		ORD DEPT
Zenith Radio Corporation Chicago, Illinois Attn: Hugh Robertson, Executive Vice-Pres.		AAF

(3) PROPULSION

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Aerojet Engineering Corp. Azusa, California Attn: K.F. Mundt	Bureau of Aeronautics Rep. 15 South Raymond Street Pasadena, California	BUAER
Armour Research Foundation Technical Center, Chicago 16, Illinois Attn: Mr. W. A. Casler		ORD DEPT
Arthur D. Little, Inc. 30 Memorial Drive, Cambridge, Mass. Attn: Mr. Helge Holst		ORD DEPT
Battelle Memorial Institute 505 King Avenue Columbus 1, Ohio Attn: Dr. B. D. Thomas		AAF & BUAER
Bendix Aviation Corp. Pacific Division, SPD West N. Hollywood, Calif.	Development Contract Officer Bendix Aviation Corp. 11600 Sherman Way N. Hollywood, Calif.	BUORD
Bendix Products Division Bendix Aviation Corporation 401 Bendix Drive South Bend 20, Indiana Attn: Mr. Frank C. Mock		AAF BUORD
Commanding General Army Air Forces Pentagon Washington 25, D.C. Attn: AC/AS-4 DRE-2E		AAF
Commanding General Air Materiel Command Wright Field Dayton, Ohio Attn: TSEPP-4B(2) TSEPP-4A(1) TSEPP-5A(1) TSEPP-5C(1) TSORE-(1)		
Commanding Officer Picatinny Arsenal Dover, New Jersey Attn: Technical Division		ORD DEPT

D. COMPONENT CONTRACTORS (Cont'd)

(3) PROPULSION

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Commanding Officer Watertown Arsenal Watertown 72, Massachusetts. Attn: Laboratory.		ORD DEPT
Continental Aviation and Engr. Corp. Detroit, Michigan	Bureau of Aeronautics Rep. 11111 French Road Detroit 5, Michigan	BUAER & AAF
Curtiss-Wright Corporation Propeller Division Caldwell, New Jersey Attn: Mr. C. W. Chillson		AAF
Experiment, Incorporated Richmond, Virginia Attn: Dr. J. W. Mullen, II	Development Contract Officer P.O. Box 1-T Richmond 2, Virginia	BUORD
Fairchild Airplane & Engine Co. Ranger Aircraft Engines-Div. Farmingdale, L.I., New York	Bureau of Aeronautics Rep. Bethpage, L.I., N.Y.	BUAER
General Motors Corporation Allison Division Indianapolis, Indiana Attn: Mr. Ronald Hazen	Bureau of Aeronautics Rep. General Motors Corporation Allison Division Indianapolis, Indiana	BUAER
G. M. Giannini & Co., Inc. 285 W. Colorado St. Pasadena, California		AAF
Hercules Powder Co. Port Ewen, N.Y.	Inspector of Naval Material 90 Church Street New York 7, New York	BUORD
Marquardt Aircraft Company Venice, California Attn: Dr. R. E. Marquardt	Bureau of Aeronautics Rep. 15 South Raymond Street Pasadena, California	AAF BUAER
Menasco Manufacturing Co. 805 E. San Fernando Blvd. Burbank, California Attn: Robert R. Miller Exec. Vice-Pres.		AAF
New York University Applied Mathematics Center New York, New York Attn: Dr. Richard Courant	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Office of Chief of Ordnance Ordnance Research & Development Div. Rocket Branch Pentagon, Washington 25, D.C.		ORD DEPT
Polytechnic Institute of Brooklyn Brooklyn, New York Attn: Mr. R.P. Harrington	Inspector of Naval Material 90 Church Street New York 7, New York	BUAER
Purdue University Lafayette, Indiana Attn: Mr. G. S. Meikel	Inspector of Naval Material 141 W. Jackson Blvd. Chicago 4, Illinois	
Reaction Motors, Inc. Lake Denmark Dover, New Jersey	Bureau of Aeronautics Resident Representative Reaction Motors, Inc. Naval Ammunition Depot Lake Denmark, Dover, N.J.	BUAER

D. COMPONENT CONTRACTORS (Cont'd)

(3) PROPULSION

CONTRACTOR	TRANSMITTED VIA	COGNIZANT AGENCY
Rensselaer Polytechnic Institute Troy, New York Attn: Instructor of Naval Science		BUORD
Solar Aircraft Company San Diego 12, California Attn: Dr. M.A. Williamson		ORD DEPT
Standard Oil Company Esso Laboratories Elizabeth, New Jersey	Development Contract Officer Standard Oil Company Esso Laboratories, Box 243 Elizabeth, New Jersey	BUORD
University of Virginia Physics Department Charlottesville, Virginia Attn: Dr. J. W. Beams	Development Contract Officer University of Virginia Charlottesville, Virginia	BUORD
University of Wisconsin Madison, Wisconsin Attn: Dr. J.O. Hirschfelder	Inspector of Naval Material, 141 W. Jackson Blvd. Chicago 4, Illinois	BUORD
Westinghouse Electric Co. Essington, Pennsylvania	Bureau of Aeronautics Resident Representative Westinghouse Electric Corp. Essington, Pennsylvania	BUAER
Wright Aeronautical Corp. Woodridge, New Jersey	Bureau of Aeronautics Rep. Wright Aeronautical Corp. Woodridge, New Jersey	BUAER
Bethlehem Steel Corp. Shipbuilding Division Quincy 69, Mass. Attn: Mr. B. Fox	Supervisor of Shipbuilding, USN Quincy, Mass.	BUAER