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FAILURE CRITICALITY ANALYSIS FOR TYPE B AND TYPE F WIND MEASURI--ETC(U)

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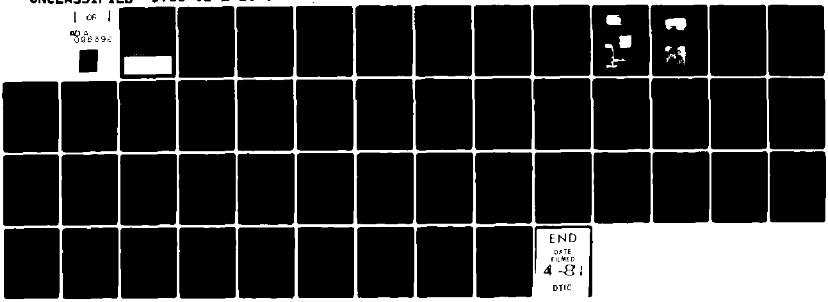

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FAILURE CRITICALITY ANALYSIS FOR TYPE B AND TYPE F WIND MEASURING AND INDICATING EQUIPMENT

October 1980

Prepared for
NAVAL AIR ENGINEERING CENTER
SHIP AND SHORE INSTALLATIONS ENGINEERING DEPARTMENT
LAKEHURST, NEW JERSEY 08733
under Contract N68335-79-C-2059

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Prepared for

Naval Air Engineering Center
Ship and Shore Installations Engineering Department
Lakehurst, New Jersey 08733

under Contract N68335-79-C-2059

by

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ABSTRACT

This report presents the results of a failure criticality analysis performed for wind measuring and indicating equipment installed on Navy ships. The effort was performed by ARINC Research Corporation for the Ship and Shore Installations Engineering Department of the Naval Air Engineering Center, Lakehurst, New Jersey, under Contract N68335-79-C-2059.

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CHAPTER ONE

INTRODUCTION

This report presents the results of a failure criticality analysis of wind measuring and indicating equipment installed on Navy ships. The effort was performed by ARINC Research Corporation for the Ship and Shore Installations Engineering Department of the Naval Air Engineering Center (NAEC), Lakehurst, New Jersey, under Contract N68335-79-C-2059.

All Navy ships are equipped with a wind measuring and indicating system, which provides continuous visual indications of wind direction and speed. It also provides representative electrical signals for computation of flight deck crosswind and headwind conditions, computation of wind vectors for weapon launch systems, and record-keeping by meteorological equipment.

Erroneous indications of wind direction and speed or complete loss of system signals can have serious consequences. Several accidents and near accidents involving aircraft have been, in part, attributed to problems associated with the wind measuring and indicating equipment.

In an attempt to better define these problems and minimize their effects, NAEC contracted with ARINC Research to perform an investigative study of the maintenance and support requirements for the wind measuring and indicating equipment. One of the tasks of this effort included a failure criticality analysis identifying those failure modes having a safety impact. This report contains the findings of the failure criticality analysis.

Chapter Two presents a description of the wind measuring and indicating equipment, and Chapter Three discusses our approach to accomplishing the failure criticality analysis. Chapter Four presents the detailed results of the analysis, including a description of synchro failure modes and identification of failure-significant items having a potential safety impact. Chapter Five presents the conclusions of the analysis, and the Appendix provides the rationale for developing failure rate estimates for selected items in the wind measuring and indicating system.

CHAPTER TWO

EQUIPMENT DESCRIPTION

Two types of wind measuring and indicating systems are used for ship installations -- Type B and Type F. The systems are functionally similar, the primary difference being that the Type B system operates on 60 Hz electric power while the Type F system operates primarily on 400 Hz electric power.

Both the Type B and Type F wind measuring and indicating systems include a detector, a transmitter, and an indicator (see Figure 1). On aircraft carriers (CVs) the system also includes a crosswind/headwind computer and a crosswind/headwind indicator (see Figure 2).

The detector is mounted high in the ship's structure, on a yardarm, to sense free stream wind flow. Wind direction is transmitted from the detector by a direction synchro which is positioned by the detector's vane assembly. Wind speed is transmitted from a speed synchro mounted in the head of the detector. An impeller type rotor is geared to a speed synchro, which generates a rotational output signal proportional to wind speed. The resulting wind speed signal is transmitted via a set of electrical slip ring contacts. The wind direction and speed output from the detector are sent to the transmitter for processing. On most ships, the transmitter is mounted on a bulkhead in the interior communications (IC) compartment. The wind direction portion of the transmitter functions essentially as a servo unit. Angular displacements of the direction synchro are amplified and transmitted as synchro signals to indicate wind direction. The wind speed portion of the transmitter functions as an integrator that measures the rotary motion of the speed synchro and displaces the transmitting synchros angularly in proportion to wind speed. The wind direction and speed output signals from the transmitter are, in turn, sent to indicators and other equipment for ship navigation, weapon launch systems, aircraft operations (flight deck crosswind and headwind conditions on CVs), and record-keeping by meteorological equipment throughout the ship.

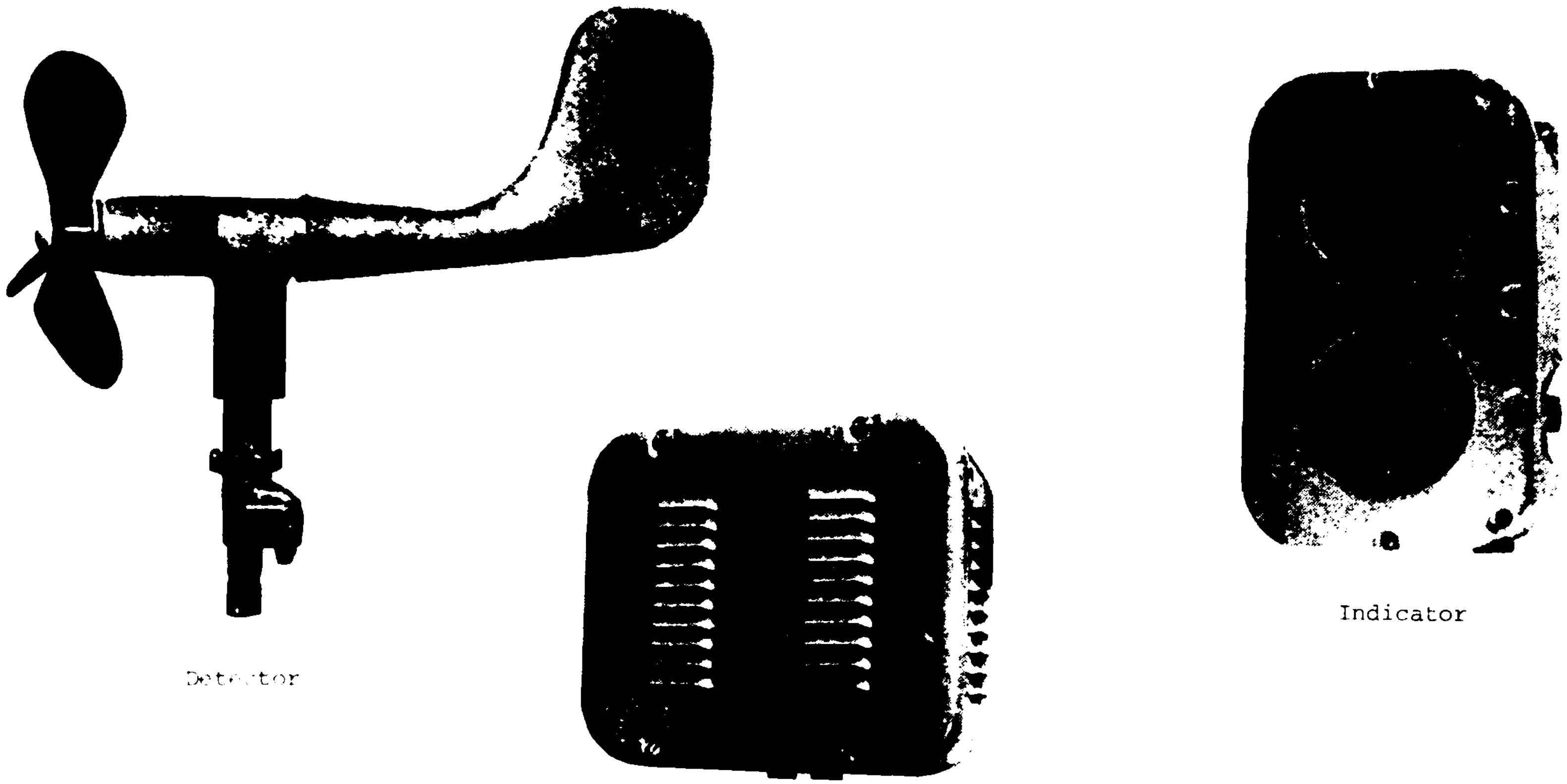
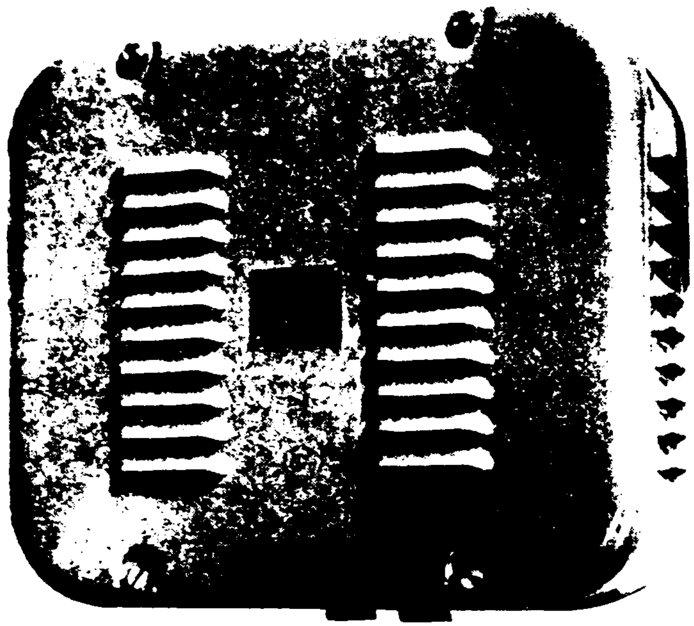
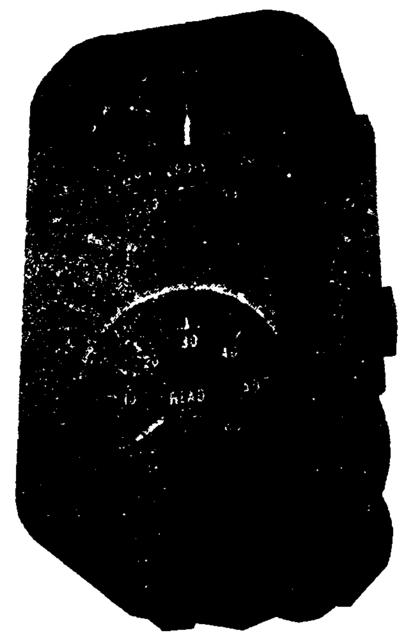


Figure 1. WIND MEASURING AND INDICATING EQUIPMENT



Computer



Indicator

Figure 2. CROSSWIND/HEADWIND COMPUTER AND CROSSWIND/HEADWIND INDICATOR

CHAPTER THREE

APPROACH

Two basic modes of malfunction are experienced by the wind measuring and indicating equipment. The first is a total failure rendering the system inoperative. This type of failure is easily identified, permitting appropriate corrective action to be taken. The second mode of malfunction is that associated with a system adjustment or alignment error (e.g., the indicated and actual wind directions are different) in which the equipment appears to be operating satisfactorily, but in actuality is providing erroneous data. This mode of failure is more detrimental than a total failure, because improper operation cannot be readily identified.

Accurate and reliable operation of wind measuring and indicating equipment is vital to ship operations. Wind measuring equipment was considered contributory to several accidents and near accidents involving carrier landings. As a result, tests were conducted to determine the effects of crosswind conditions on carrier landings. During these tests, it was found that crosswind conditions resulting from wind direction errors as small as 10° had degrading effects on carrier landings for some types of aircraft.

The failure criticality analysis contained herein is not a standard failure mode and effects analysis (FMEA) that identifies all failure modes for each individual piece/part and determines the effects those failure modes have on equipment operation. Given the equipment's age and maturity, an FMEA is unwarranted. The primary goal of the failure criticality analysis was first to identify system failure modes that have a potential safety impact and then to determine the specific component or piece/part that could cause the equipment malfunction. This includes not only hard failures that render the equipment inoperative, but adjustment and alignment failures that frequently go unnoticed. The analysis identifies those contributing items and discusses their failure modes and the related symptoms and effects. Additionally, a relative measure of the failure severity, likelihood of occurrence, and criticality is provided. The following individual tasks were accomplished in performance of the failure criticality analysis:

Task 1 - Functional Design Review
Task 2 - Review of Component and Piece/Part Usage Data
Task 3 - Identification of Critical Failure Items and Modes

Task 4 - Definition of Failure Symptoms and Effects
Task 5 - Establishment of Levels of Severity
Task 6 - Determination of Failure Probability
Task 7 - Development of Criticality Index

Task 1 - Functional Design Review

The functional design review included gaining familiarity with the theory of equipment operation for both the Type B and Type F systems and was directed toward determining specific system failure modes having a safety impact and identifying the respective subassemblies, components, and piece/parts whose failure could cause the system malfunction. Study of technical documentation and engineering drawings and attendance at a two-week training course supported the functional design review. Additionally, we interviewed cognizant user, maintenance, and manufacturer personnel.

Task 2 - Review of Component and Piece/Part Usage Data

We reviewed piece/part usage data to determine the frequency of replacement. Data included in the review included piece/part procurement information from the manufacturer (the Bendix Corporation), CASREP data, and fleet piece/part replacement data from the Ship Parts Control Center (SPCC). The purpose of the review was to determine failure rates and probabilities of occurrence for selected failure-significant items.

Task 3 - Identification of Critical Failure Items and Modes

On the basis of the results of the functional design review and review of component and piece/part usage data, we listed those items which were likely failure candidates and determined their respective failure modes.

Task 4 - Definition of Failure Symptoms and Effects

Each of the failure candidates and its failure modes were analyzed to determine the recognizable behavior pattern or symptom that indicates that a failure or discrepancy has occurred. This effort included consideration of symptoms at both the unit and the overall system levels. The analysis also included defining the resulting effects on system operation.

Task 5 - Establishment of Levels of Severity

A level of severity was assigned to each of the failure candidates. The level of severity is a classification assigned on the basis of the effect of the failure on the operation of the system. Classifications of the levels of severity of failures within the wind measuring and indicating equipment are as follows:

Level 1, Insignificant - An insignificant item failure is one that has no immediate degrading effect on the functional operation or output of the system (e.g., a burned-out indicator panel light). Level 1 failures will not be considered in this report.

Level 2, Minor - A minor item failure has a negligible effect on system functional operation and output. It is usually easily identifiable and can be corrected by in-place adjustment, alignment, or removal and replacement.

Level 3, Major, Recognizable - This level of failure has a degrading or catastrophic effect on system functional operation and output; however, the discrepancy is easily recognizable and appropriate corrective action can be taken.

Level 4, Major, Unrecognizable - This level of failure has a degrading effect on the functional operation of the system and accuracy of the output, but the failure does not exhibit behavioral characteristics that are easily recognized (e.g., a synchro slipping from electrical zero because its attachment hardware has loosened). The level 4 failure classification has safety-impact ramifications.

Task 6 - Determination of Failure Probability

The probability of occurrence for each item failure was calculated by use of SPCC best replacement factors (BRFs) derived from our review of the component and piece/part usage data. The probability of occurrence is based on a one-year time period, which is the standard time baseline used by SPCC in supporting Navy ships. The probability of occurrence (P_O) is calculated by means of this equation:

$$P_O = 1 - e^{-BRF}$$

The probabilities of occurrence of item failures were then grouped into four individual probability levels as follows:

Level 1, Very Low - Probability of occurrence was equal to or less than 0.01 for a single failure during a one-year period.

Level 2, Low - Probability of occurrence was greater than 0.01 but not greater than 0.10 for a single failure during a one-year period.

Level 3, Medium - Probability of occurrence was greater than 0.10 but not greater than 0.22 for a single failure during a one-year period.

Level 4, High - Probability of occurrence was greater than 0.22 for a single failure during a one-year period.

Task 7 - Development of Criticality Index

The criticality of an item failure is the combination of its probability of occurrence and its level of severity. On the basis of reliability alone, a specific item failure may have a high probability of occurrence but have an insignificant effect on the system's functional operation. Hence, the true effect of an item failure on the functional operation of a system is best defined by the combination of its likelihood of occurring and severity of results if it does occur.

The criticality index provides a means of comparing each individual item failure with all others and with respect to the system's functional operation and criticality relating to its effect on safety.

CHAPTER FOUR

RESULTS

4.1 GENERAL

Output signals from the wind measuring and indicating system representative of wind direction and speed are vital to ship operations for computation of flight deck crosswind and headwind conditions, computation of wind vectors for weapon systems, and record-keeping by meteorological equipment. Errors in, or complete loss of, these signals can have serious consequences, particularly for aircraft operations in which wind signal errors can affect safety. Tests have shown that crosswind errors greater than 10° can have degrading effects on carrier landings for some types of aircraft.

On the basis of a functional review of the system design, we concluded that system failures affecting safety applied primarily to aircraft operations. System failure modes having a potential safety impact were identified as errors in wind direction and, to a lesser degree, wind speed. Failures of components and piece/parts whose behavioral characteristics are such that system failures are not readily recognized are classified as level 4 in severity.

We reviewed the functional operation of units making up the wind measuring and indicating system to identify failure-significant items* and their failure modes and determine their level of severity. Usage data or demand rates provided a quantitative index by which the probability of failure could be estimated.

Since many of the wind equipment problems are associated with synchros, a separate discussion (Section 4.2.6.4) is provided on them and their failure modes and symptoms.

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*A failure-significant item is defined as any component, piece/part, or integral piece/parts group having a demonstrated failure rate that significantly degrades equipment reliability and creates a requirement for a replacement or repair action.

4.2 FAILURE-SIGNIFICANT ITEMS

Failure-significant items within units of the wind measuring and indicating system are identified in Table 1. For each item, the table shows the ratio of the experienced yearly demand rate to its total in-service population (BRF/λ*), the estimated probability of occurrence (P_o) of a failure, and the level of severity (L_S). The table does not include the crosswind/headwind indicator nor the wind direction and speed recorder. The crosswind/headwind indicator has exhibited excellent reliability. The only components in the indicator that are considered failure-significant are the crosswind and headwind microammeters and, due to their demonstrated high reliability, no BRF has been established. Because of this factor and because failure of one of the microammeters would be recognizable without any effect on safety, we decided not to list the crosswind/headwind indicator. The wind direction and speed recorder is used for record-keeping purposes and has no effect on safety so it was not considered.

The function of individual failure-significant items (as identified in Table 1) and their failure modes, symptoms, effects, and level of severity are discussed in the following paragraphs.

4.2.1 Detector

The Type B and Type F detectors are dual purpose units each employing two synchros for transmitting wind speed and wind direction signals to the transmitter unit. In external shape and appearance and system function, the Type B and Type F detectors are the same. The synchros in the Type B operate on 60 Hz and in the Type F on 400 Hz. Basically, all other functional details are the same; however, many parts are not interchangeable, and although they may serve identical functions, they have different BRFs. Hence, Table 1 presents the quantitative indexes individually for the Type B and Type F detectors.

4.2.1.1 Rotor Assembly, Wind Speed

A three-bladed screw-type rotor assembly or impeller is used on the detector to sense wind speed. The rotor assemblies used on both the Type B and Type F detectors are identical. Physical damage or breakage of one or more of the blades, generally resulting from abuse or mishandling, is the primary failure mode. Failure of a blade can unbalance the rotor assembly and result in an erroneous (low) indication of wind speed. The start-up wind speed required to overcome the torque associated with a rotor

*The provisioning of spares aboard ship to accommodate equipment failures is accomplished by SPCC using a quantitative index called a "best replacement factor" (BRF), which relates directly to a failure rate (λ). The BRF represents the ratio of the experienced yearly demand rate for an item to the total in-service population of the item. Should the BRF equal or exceed 0.25 for a vital item or piece/part of a vital next higher assembly, the item will normally be provisioned aboard ship.

Table 1. FAILURE-SIGNIFICANT ITEMS			
Item	BRF/λ	P_o	L_s
Detector, Type B	1.671	0.812	
Rotor Assembly, Wind Speed	0.100	0.095	3
Gear Train, Wind Speed	0.944[1]*	0.611	3
Synchro, Wind Speed	0.028	0.028	3
Electrical Contact/Slip Ring Assembly	0.093[2]	0.089	3
Vane Assembly	0.003	0.003	4
Bearings, Vane Shaft	0.440[3]	0.356	3
Synchro, Wind Direction	0.028	0.028	4
Connector	0.035	0.034	3
Detector, Type F	0.920	0.601	
Rotor Assembly, Wind Speed	0.100	0.095	3
Gear Train, Wind Speed	0.199[4]	0.180	3
Synchro, Wind Speed	0.025	0.025	3
Electrical Contact/Slip Ring Assembly	0.093[2]	0.089	3
Vane Assembly	0.003	0.003	4
Bearings, Vane Shaft	0.440[3]	0.356	3
Synchro, Wind Direction	0.025	0.025	4
Connector	0.035	0.035	3
Transmitter, Type B	1.702	0.818	
Wind Direction Assembly	0.481	0.095	
Synchro, Control Transformer	0.100	0.095	4
Inductor	0.003	0.003	3
Transformer	0.008	0.008	3
Amplifier, Servo	0.247[5]	0.219	3
Motor, Servo, Reversible	0.023	0.023	3
Gear Train, Servo	0.059[6]	0.058	3
Synchro, Transmitter	0.031	0.031	4
Connector	0.010	0.010	3
Wind Speed Assembly	1.221	0.705	
Synchro, Receiver	0.028	0.028	3
Gear, Spur	0.050	0.049	3
Motor, Synchronous	0.130	0.122	3
Integrator, Subassembly, Roller-Disc	0.892[7]	0.590	3
Gear Train, Disc Drive	0.080[8]	0.077	3
Synchro, Transmitter	0.031	0.031	4
Connector	0.010	0.010	3
Transmitter, Type F	2.002	0.865	
Wind Direction Assembly	0.404	0.332	
Synchro, Control Transformer	0.021	0.021	4
Amplifier, Magnetic	0.036	0.035	3
Motor, Servo	0.200	0.181	3

*Footnotes explaining BRF/λ rationale appear in the appendix.

(continued)

Table 1. (continued)

Item	BRF/λ	P_o	L_s
Wind Direction Assembly (continued)			
Gear Train, Servo	0.030 [9]	0.030	3
Synchro, Transmitter	0.029	0.029	4
Synchro, Transmitter	0.078 [10]	0.075	4
Connector	0.010	0.010	3
Wind Speed Assembly	1.598	0.798	
Synchro, Control Transformer	0.021	0.021	3
Gear Train, Wind Speed	0.078 [10]	0.075	3
Amplifier, Magnetic	0.036	0.035	3
Motor, Servo, Reversible	0.140	0.131	3
Motor, Synchronous	0.110	0.104	3
Integrator Subassembly, Roller-Disc	0.830 [11]	0.564	3
Synchro, Transmitter	0.029	0.029	4
Gear	0.006	0.006	3
Synchro, Transmitter	0.078	0.075	4
Connector	0.010	0.010	3
Relay	0.260	0.229	3
Indicator, Type F/60	0.109	0.103	
Synchro, Receiver, Wind Direction	0.050	0.049	2
Synchro, Receiver, Wind Speed	0.050	0.049	2
Connector	0.009	0.009	2
Crosswind/Headwind Computer	1.211	0.702	
Wind Speed Circuit	0.686	0.496	
Synchro, Control Transformer	0.100	0.095	4
Inductor	0.003	0.003	3
Transformer	0.008	0.008	3
Amplifier, Servo	0.247 [5]	0.219	3
Motor, Servo, Reversible	0.023	0.023	3
Gear Train, Servo	0.030 [9]	0.030	3
Potentiometer, Power	0.047	0.046	4
Transformer, Power	0.006	0.006	3
Power Supply, DC	0.222 [12]	0.199	3
Wind Direction Circuit	0.525	0.408	
Synchro, Control Transformer	0.100	0.095	4
Inductor	0.003	0.003	3
Transformer	0.008	0.008	3
Amplifier, Servo	0.247 [5]	0.219	3
Motor, Servo, Reversible	0.023	0.023	3
Gear Train, Servo	0.030 [9]	0.030	3
Potentiometer, Sine-Cosine	0.096	0.092	4
Connectors	0.018	0.018	3

unbalance will be somewhat higher than under normal conditions. The failure mode is considered recognizable and of level 3 severity, with little effect on safety.

4.2.1.2 Gear Train, Wind Speed

The rotor assembly is connected to a synchro through a reduction gear train consisting of gears, shafts, and bearings. Failure modes of the gear train include high mechanical friction or seizure resulting from corroded or worn bearings; corroded, burred, worn, or otherwise damaged gear teeth; and a worn shaft, lack of lubricant, or binding or tight gear engagement. These failure modes will cause a decrease or loss of wind speed indication. The failure modes are considered recognizable and of level 3 severity with little effect on safety.

4.2.1.3 Synchro, Wind Speed

A synchro, geared to the rotor assembly, provides a rotational output signal whose rate is a function of the wind speed. Failure modes and symptoms associated with synchros are discussed in detail in Section 4.2.6.4 and *MIL-HDBK-225, Military Standardization Handbook, Synchros - Description and Operation*. A failure mode, typical of synchro installations, that is not applicable to the wind speed synchro, is that of zero alignment. Since the output of the wind speed synchro is a rate signal proportional to wind speed and not a position signal, zero alignment is not required. Failure of the wind speed synchro will show up as a loss of a wind speed indication or erratic operation of the transmitter's integrator subassembly and related wind speed indication. Failure modes associated with the wind speed synchro are considered recognizable and of level 3 severity with little effect on safety.

4.2.1.4 Electrical Contact/Slip Ring Assembly

The wind speed synchro output signal is transmitted through an electrical contact/slip ring assembly consisting of six electrical contact sets. Failure modes associated with the electrical contact/slip ring assembly consist of contact sets opening or shorting to ground. The symptoms associated with these failures will show up as loss of a wind speed indication or erratic operation of the transmitter's integrator subassembly and related wind speed indication. The failure modes are considered recognizable and of level 3 severity with little effect on safety.

4.2.1.5 Vane Assembly

The vane assemblies for the Type B and Type F detectors are virtually identical with the exception of the material from which they are fabricated. The Type B vane assembly is Monel and the Type F vane is fiberglass. The vane assemblies are coupled to the wind direction synchro and their angular position represents the wind direction. The demand rate for vane assemblies is very low as the only failure mode the vane is subject to is deformation resulting from abuse or mishandling. However, the indication of direction provided by the vane assembly is a result from the wind direction, and any physical deformation of the vane can induce an unknown resultant error into the wind measuring system. Although the likelihood of encountering this problem is low, the failure is not easily recognizable, and it can have a safety impact on aircraft operations. As a result, the severity of the failure mode is classified as level 4.

4.2.1.6 Bearings, Vane Shaft

The vane assembly is coupled to the wind direction synchro, which is part of, and is mounted in, the vane housing and shaft assembly. As the wind positions the vane assembly, the vane housing and shaft assembly rotates on bearings that suspend the vane shaft. Failure modes of the bearings include high mechanical friction and seizure and subsequent loss or sluggishness of the wind direction indication. The failure mode is considered recognizable and of level 3 severity with little effect on safety.

4.2.1.7 Synchro, Wind Direction

A synchro, coupled to the vane assembly, provides a position output signal that represents wind direction. Failure modes and symptoms associated with the wind direction synchro are discussed in detail in Section 4.2.6.4 and MIL-HDBK-225. Failure of the wind direction synchro will show up as loss of, or an erroneous, wind direction indication. Under worst-case conditions, some failure modes of the wind direction synchro can go unrecognized and therefore affect the safety of aircraft operations. The severity of failures associated with the wind direction synchro are classified as level 4.

4.2.1.8 Connector

An electrical connector located at the lower end of the vane housing and shaft assembly provides for removal and replacement of the detector without disturbing the incoming and outgoing wires or alignment. Failure modes associated with connectors generally consist of loss of electrical contact due to corrosion or mishandling that results in bent pins. Since most connector problems are associated with physical mishandling (unit removal and replacement), the failure is considered easily recognizable during subsequent system check-out and test. Hence, the failure of a connector is classified as level 3 in severity with little effect on safety.

4.2.2 Transmitter

Both the Type B and Type F transmitters consist of two assemblies: a wind direction assembly and a wind speed assembly. Although there are physcial differences between the assemblies in the two transmitter types, their functional operation is the same. The wind direction assemblies in both the Type B and Type F transmitters consist of a closed-loop servo system that positions transmitting synchros (60 Hz synchro in the Type B unit, and 60 Hz and 400 Hz synchros in the Type F unit). In the wind speed assemblies, the wind speed synchro's rate signal is translated to a single angular synchro position representative of wind speed. This translation is accomplished by a roller-disc integrator that positions the transmitting synchros (again, a 60 Hz synchro is used in the Type B unit, and 60 Hz and 400 Hz synchros are used in the Type F unit). The wind speed assembly in the Type B transmitter does not have a closed-loop servo system. Although the two transmitter types are functionally the same, their constituent assemblies and piece/part make-up differ considerably. Table 1 presented the quantitative indexes for each of the Type B and Type F transmitters.

4.2.2.1 Wind Direction Assembly

Since the wind direction assemblies used in both the Type B and Type F transmitters are functionally the same, their constituent failure-significant items are discussed collectively in the subsequent paragraphs. Those items applicable to either the Type B or Type F configuration only are identified as such.

4.2.2.1.1 Synchro, Control Transformer

A control transformer synchro is similar to an ordinary synchro except that its rotor winding is designed to feed a voltage signal into a high impedance amplifier used in servo systems. The wind direction assemblies in both transmitter types employ control transformer synchros. The control transformer synchro responds to changes in the detector's vane shaft position and provides a corresponding correction signal to the amplifier in the servo system. Failure modes and symptoms associated with control transformer synchros are discussed in Section 4.2.6.4 and MIL-HDBK-225. Failure of the wind direction control transformer synchro will show up as loss of, or an erroneous, wind direction indication. Under worst-case conditions, some failure modes of the wind direction synchro can go unrecognized and affect the safety of aircraft operations. Therefore, failures associated with the wind direction control transformer synchro are classified as being of level 4 severity.

4.2.2.1.2 Inductor (Type B)

An inductor, in series with the servo amplifier input transformer, compensates for inherent phase shift in the control transformer synchro. The inductor forms part of the servo system used in the Type B transmitter's wind direction circuit and the crosswind/headwind computer's wind direction and wind speed circuits. Failure of the inductor, by shorting to ground or opening, will result in loss of the position error signal input to the servo amplifier, which will show up as loss of subsequent rotational response of the respective servo system and driven components: the wind direction transmitting synchro in the Type B transmitter and the sine-cosine potentiometer (wind direction) or linear potentiometer (wind speed) in the crosswind/headwind computer. Failure of the inductor is considered recognizable and of level 3 severity.

4.2.2.1.3 Transformer (Type B)

A transformer is used to provide a push-pull signal input to the servo amplifier; it also isolates any dc in its secondary (servo amplifier) winding from the control transformer synchro. The transformer forms part of the servo system in the Type B transmitter's wind direction circuit and the crosswind/headwind computer's wind direction and wind speed circuits. Failure of the transformer, by shorting or opening, will result in loss of the position error signal input to the servo amplifier, which will show up as loss of subsequent rotational response of the respective servo system and driven components: the wind direction transmitting synchro in the Type B transmitter and the sine-cosine potentiometer (wind direction) or linear potentiometer (wind speed) in the crosswind/headwind computer. Failure of the transformer is considered recognizable and of level 3 severity.

4.2.2.1.4 Amplifier, Servo (Type B)

A solid-state push-pull servo amplifier provides the necessary power to drive the reversible servo motor in either the clockwise or counter-clockwise direction. Servo amplifiers used in the Type B transmitter's wind direction circuit and the crosswind/headwind computer's wind direction and wind speed circuits are identical. Failure by shorting or opening of a component within the servo amplifier will result in either loss of rotational response of the servo system (the servo system will respond in one direction only) or the servo system will drive continuously in a clockwise or counterclockwise direction. The failure mode will show up in the behavior of the wind direction and speed indicator or the crosswind/headwind indicator, or both. Failure of the servo amplifier is considered recognizable and of level 3 severity.

4.2.2.1.5 Amplifier, Magnetic (Type F)

An encapsulated magnetic amplifier is used in the servo system of the Type F wind direction and wind speed assemblies in lieu of the solid-state servo amplifier used in the Type B equipment. The magnetic amplifier controls power to the reversible servo motor to drive it in either direction. Failure of the magnetic amplifier will result in loss of rotational response of the respective servo system. The behavioral response will show up in the wind direction and speed indicator. Failure of the servo amplifier is considered recognizable and of level 3 severity.

4.2.2.1.6 Motor, Servo, Reversible

A reversible servo motor, controlled by the output of the servo amplifier or magnetic amplifier, provides the torque required to drive the respective servo gear train and driven components: the wind direction synchros in the Type B and Type F transmitter; the wind speed input to the roller-disc integrator in the Type F transmitter; and the linear potentiometer (wind speed circuit) and sine-cosine potentiometer (wind direction circuit) in the crosswind/headwind computer. Failure modes of the servo motor include shorted and open windings and high mechanical friction or seizure of the armature. These failure modes will show up as loss or sluggishness of subsequent rotational response of the respective servo system or a capability of driving in one direction only. Failure of the servo motor is considered recognizable and of level 3 severity.

4.2.2.1.7 Gear Train, Servo

In both the Type B and Type F wind direction assemblies, a gear train driven by the reversible servo motor drives the rotor of the control transformer synchro to a null and positions other components in the respective servo system. Failure modes of the gear train include high mechanical friction or seizure resulting from burred or damaged teeth, corrosion, worn shaft pivots, lack of lubricant, and binding or tight gear engagement. These failure modes will show up as loss of motion or sluggishness of the rotational response of the respective servo system. Failure of a gear train is considered to be generally recognizable and of level 3 severity. An exception to the level 3 severity classification is assigned to failures associated with individual gears attached to synchros that undergo slippage or relative motion between the gear and shaft, which results in subsequent system failure due to loss of alignment. This failure mechanism is covered under the detailed discussion of synchros in Section 4.2.6.4. Relative motion between a gear and synchro shaft, and subsequent loss of alignment can result in an unrecognizable failure that affects safety and is classified as being of level 4 severity.

4.2.2.1.8 Synchro, Transmitter

Transmitter type synchros in the Type B and Type F transmitters provide positional signal outputs respresentative of wind direction and wind speed. In the wind direction assemblies, the transmitting synchros are positioned by the respective servo system. In the wind speed assemblies the synchros are positioned by the rack gear output of the roller-disc integrator subassemblies. Failure modes and symptoms associated with synchros are discussed in detail in Section 4.2.6.4 and MIL-HDBK-225. Failure of the wind direction and wind speed output synchros in both the Type B and Type F transmitters will show up as loss of or erroneous indication of wind direction or speed. Since some failure modes associated with the transmitter output synchros can go unrecognized and, as a result, affect safety, they are classified as being of level 4 severity.

4.2.2.1.9 Connector

Each of the Type B and Type F wind direction and wind speed assemblies has an electrical connector that provides for removal and replacement of the assembly without disturbing the incoming or outgoing wires. Failure modes associated with connectors consist of loss of contact due to corrosion or mishandling that results in bent pins. Since most connector problems are associated with physical mishandling during removal and replacement of the assembly, the failure mode is considered recognizable during subsequent check-out and test. Failure of the connector is considered to be of level 3 severity.

4.2.2.2 Wind Speed Assembly

The functional operation of the wind speed assemblies in the Type B and Type F transmitters are generally the same; however, there are physical differences, the most significant being that the Type B wind speed assembly does not employ a servo system but uses a receiver type synchro to drive the integrator input by means of a reduction gear. The Type F assembly does employ a servo system whose constituent components are the same as those in the Type F wind direction assembly. Failure-significant items are discussed collectively. Those items applicable to the Type B or Type F configuration only are identified.

4.2.2.2.1 Synchro, Receiver (Type B), and Control Transformer (Type F)

In the Type B wind speed assembly, a receiving type synchro rotates at the same speed as the speed synchro in the detector. The rate signal being received by the input receiver synchro is transmitted through a reduction gear train* to the input of the roller-disc integrator subassembly. The action of this synchro is functionally the same as that of the control transformer synchro used in the input of the Type F wind speed assembly (see Section 4.2.2.1.1). Failure modes and symptoms associated with synchros are discussed in detail in Section 4.2.6.4 and MIL-HDBK-225. Since the output of the wind speed receiver synchro is a rate signal proportional to wind speed and not a position signal, zero alignment is not required. Failure of the wind speed input receiver synchro (Type B transmitter) or the control transformer synchro (Type F transmitter) will show up as loss of a wind speed indication or erratic operation of the transmitter's integrator subassembly and related wind speed indication. Failure modes associated with the wind speed receiver or control transformer synchros are considered recognizable and of level 3 severity with little effect on safety.

4.2.2.2.2 Gear Train, Wind Speed (Type F)

The rate signal processed by the wind speed receiver or control transformer synchro is transmitted to the input of the roller-disc integrator via a reduction gear train.* Failure modes of the gear train include high mechanical friction or seizure resulting from corroded or worn pivots; corroded, burred, worn or otherwise damaged gear teeth; lack of lubricant; and binding or tight gear engagement. These failure modes will show up as loss of, or decreased intensity of, the wind speed indication. The failure modes are considered recognizable and of level 3 severity with little effect on safety.

4.2.2.2.3 Servo System Components (Type F)

The constituent components making up the servo system in the Type F wind speed assembly are identical to those in the Type F wind direction assembly. For the magnetic amplifier, see Section 4.2.2.1.5; for the reversible servo motor see Section 4.2.2.1.6; and for the servo gear train see Section 4.2.2.1.7.

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*In the Type B wind speed assembly, this gear train is part of the roller-disc integrator subassembly with the exception of the synchro spur gear.

4.2.2.2.4 Motor, Synchronous

In both the Type B and Type F wind speed assemblies, a constant-speed synchronous motor drives the discs in the roller-disc integrator by means of a reduction gear train. Failure modes of the synchronous motor include shorted or open windings and high mechanical friction or seizure of the rotor. These failure modes will stop disc rotation, in which case any wind speed input will cause the roller shaft to be driven to its maximum speed position. In the Type B wind speed assembly, this failure situation can cause secondary damage to the integrator by jamming the roller shaft and related mechanism. In the Type F wind speed assembly, the roller shaft will drive to the maximum speed limit and shut down by limit switch action. The failure, which can cause possible secondary damage in the Type B integrator subassembly, is recognizable and classified as being of level 3 severity.

4.2.2.2.5 Integrator Subassembly, Roller-Disc

The roller-disc integrator translates a rate of synchro rotation input, whose speed is a function of the wind speed, into a single angular displacement of the output synchro representative of wind speed. Both the Type B and Type F transmitters' wind speed assemblies employ functionally similar integrator subassemblies. Both of the integrators are complex mechanisms which have a demonstrated susceptibility to problems -- the integrators have the highest failure rate of any item in the wind measuring and indicating system. However, many of the problems with the integrators are maintenance-induced. Failure modes include damage to, or wear of, the roller shaft assembly (worn or stripped spiral gear and rack gear, worn roller, and bent shaft); worn or grooved discs; worn, stripped, or otherwise damaged gears; worn bearings and retainer; broken spring; and open or shorted limit switches. Failures of the integrator subassemblies will show up as a loss of wind speed indication, erroneous or erratic movement, or a steady but incorrect wind indication. Failure of the roller-disc integrator is recognizable and is classified as being of level 3 severity.

4.2.2.2.6 Gear Train, Disc Drive

The constant-speed output of the synchronous motor is transmitted by means of a reduction gear train to drive the discs in the roller-disc integrator. In the Type F wind speed assembly, this gear train is an integral part of the integrator; in the Type B assembly the gear train is separate. Failure modes of the reduction gear train include high mechanical friction or seizure resulting from corroded or worn pivots; corroded, burred, worn, or otherwise damaged gear teeth; lack of lubricant; and binding or tight gear engagement. These failure modes will show up much the same as loss of the synchronous motor. High mechanical friction will result in an erroneous (high) or erratic wind speed output, while seizure will stop the discs from rotating and cause the roller-shaft to drive to its maximum speed limit. That failure mode can cause secondary damage to the Type B wind speed assembly by jamming the integrator mechanism and overloading or stalling the synchronous motor. The failure is recognizable and classified as being of level 3 severity.

4.2.2.2.7 Synchro, Transmitter, Wind Speed

The wind speed transmitter synchros in the wind speed assemblies for both the Type B and Type F transmitters are identical to the wind direction assemblies (see Section 4.2.2.1.8).

4.2.2.2.8 Connector

Identical connectors are used for both the wind speed and wind direction assemblies (see Section 4.2.2.1.9).

4.2.2.2.9 Relay (Type F)

A relay installed in the Type F wind speed assembly provides protection for the roller-disc integrator subassembly in the event 60 Hz power is lost during operation or 400 Hz Power is activated before application of Hz power. Its failure is recognizable and classified as being of level 3 severity.

4.2.3 Indicator, Type F/60

The Type F/60 wind direction and speed indicator operates with both the Type B and Type F wind measuring and indicating equipment. The indicator houses a single assembly that contains only three failure-significant items: two receiver synchros (wind direction and speed) and a connector.

The wind direction and wind speed synchros are identical receiver synchros that accept wind direction and wind speed synchro input signals from the output synchros in the Type B or Type F transmitters. Pointers, fastened to the rotor shafts of the synchros, indicate wind direction and wind speed on separate circular dials. Failure modes and symptoms associated with the synchros are discussed in Section 4.2.6.4 and MIL-HDBK-225. Failure of one of the synchros will show up as loss of its indication (wind direction or wind speed).

The wind direction and speed assembly is equipped with a connector to facilitate removal and replacement. Failure of the connector is most commonly the result of physical mishandling during removal and installation, i.e., bent pins or broken wires, causing loss of contact or shorting.

The indicator failure modes that include both the synchros and the connector are considered easily recognizable. Failure of either a synchro or connector in the indicator affects only that specific indicator and not the entire system as would a synchro or connector failure in the transmitter or detector. Therefore, the failures are classified as being of level 2 severity.

4.2.4 Crosswind/Headwind Computer

The crosswind/headwind computer operates in conjunction with both Type B and Type F wind measuring and indicating equipment. The computer consists of a wind speed and wind direction circuit and provides outputs representative of crosswind and headwind speeds relative to the straight deck or angle deck of an aircraft carrier. Failure-significant items making up the crosswind/headwind computer and their respective quantitative indexes were presented in Table 1.

4.2.4.1 Wind Speed Circuit

The wind speed circuit receives a synchro position signal from the Type B or Type F transmitter representing wind speed. Through the use of a control transformer and servo system, a linear potentiometer is positioned to provide a component of the dc voltage from the dc power supply (representing wind speed) as excitation to the sine-cosine potentiometer in the wind direction circuit.

4.2.4.1.1 Servo System Components, Wind Speed Circuit

Components of the wind speed servo system in the crosswind/headwind computer are the same as for the servo system in the Type B transmitter's wind direction assembly already discussed: control transformer synchro, see Section 4.2.2.1.1; inductor, see Section 4.2.2.1.2; transformer, see Section 4.2.2.1.3; servo amplifier, see Section 4.2.2.1.4; reversible servo motor, see Section 4.2.2.1.6; and servo gear train, see Section 4.2.2.1.7.

4.2.4.1.2 Potentiometer, Linear

A precision linear potentiometer, driven by the computer's wind speed servo system, provides a dc voltage proportional to wind speed as excitation to the sine-cosine potentiomenter in the wind direction circuit. The failure modes of the linear potentiometer are opening of the resistive element or alignment slippage of the case or shaft/wiper, either of which causes a loss or change to the dc wind speed signal. Under worst-case conditions, the failure will show up as an unrecognizable erroneous wind speed input affecting the crosswind and headwind indication. This can have an effect on the safety of aircraft operations. As a result, failure of the linear potentiometer is classified as being of level 4 severity.

4.2.4.1.3 Transformer, Power

The power transformer reduces the 115 Vac source voltage to 28.5 Vac for use by the dc power supply. Failure of the transformer, by shorting or opening, will result in loss of voltage to the dc power supply and loss of the dc voltage output that is provided to the linear potentiometer where a component to represent wind speed is selected. Loss of the voltage would be immediately recognizable, showing up as loss of the crosswind/headwind indication. Failure of the transformer is classified as being of level 3 severity.

4.2.4.1.4 Power Supply, DC

The dc power supply converts the 28.5 Vac power transformer output to regulated 26 Vdc for the precision linear potentiometer. Failure modes include voltage drift or loss of the dc voltage output. Voltage drift would have very little effect on crosswind/headwind indications, while complete loss of dc voltage would be immediately recognizable. As a result, failure of the dc power supply is classified as being of level 3 severity.

4.2.4.2 Wind Direction Circuit

The wind direction circuit receives a synchro position signal from the Type B or Type F transmitter representative of wind direction. Through the use of a control transformer and servo system, a sine-cosine potentiometer wiper is positioned to represent the wind direction. Since the sine-cosine potentiometer receives a dc excitation voltage representative of wind speed from the wind speed circuit, the positioning of the potentiometer wiper provides dc voltage outputs representative of crosswind and headwind components of the wind across the flight decks of an aircraft carrier. The outputs of the sine-cosine potentiometer are provided to crosswind/headwind indicators.

4.2.4.2.1 Servo System Components, Wind Direction

Components of the wind direction servo system in the crosswind/headwind computer are identical to those making up the servo system in the Type B transmitter's wind direction assembly, previously discussed: control transformer synchro, see Section 4.2.2.1.1; inductor, see Section 4.2.2.1.2; transformer, see Section 4.2.2.1.3; servo amplifier, see Section 4.2.2.1.4; reversible servo motor, see Section 4.2.2.1.6; and servo gear train, see Section 4.2.2.1.7.

4.2.4.2.2 Sine-Cosine Potentiometer

The sine-cosine potentiometer develops voltages that are representative of the crosswind (sine) and headwind (cosine) components of the wind conditions relative to an aircraft carrier's flight decks. The potentiometer contains four stacked sections: two sections are for the sine-cosine functions of the straight deck, and two sections, displaced angularly by 10 degrees, are for the sine-cosine functions of the angle deck. All sections are simultaneously driven on a common shaft by the wind direction servo system. The failure modes of the sine-cosine potentiometer are opening of a resistive section, or alignment slippage of the drive shaft/wiper or case, either of which can cause significant changes in the respective dc output voltages. Under worst-case conditions, the failure will show up as an unrecognizable erroneous crosswind/headwind indication that could affect the safety of aircraft operations. Consequently, failure of the sine-cosine potentiometer has a level 4 severity classification.

4.2.4.3 Connectors

Two identical ribbon contact connectors are used in the crosswind/headwind computer to permit removal and replacement of the chassis assembly without disturbing the incoming and outgoing wires. Failure modes associated with connectors consist of loss of contact due to corrosion or physical damage resulting from mishandling. Failure of the connectors in the cross/headwind computer is considered recognizable and of a level 3 severity.

4.2.5 Crosswind/Headwind Indicator

As previously indicated, the crosswind/headwind indicator is not listed in Table 1 because it is not considered a failure-significant item. The indicator has demonstrated a high degree of reliability. Additionally, failure of an indicator would be easily recognizable and affect that indicator only.

4.2.6 Synchros, General, Wind Measuring and Indicating System

Synchros of both 60 Hz and 400 Hz electrical configuration are used throughout the wind measuring and indicating system. Since the basic failure modes and symptoms and problem recognition concepts are essentially the same for 60 Hz and 400 Hz synchros, no distinction is made.

4.2.6.1 Transmitter Synchro

Transmitter synchros, sometimes called synchro generators, consist of a single winding rotor and a stator having three windings, each displaced 120 electrical degrees from the other. Voltages induced into the stator windings by the rotor winding represent the instantaneous angular position of the controlling shaft of the rotor. These stator voltages are transmitted to the respective stators of a receiver synchro and, in turn, are used to control the position of its rotor.

4.2.6.2 Receiver Synchro

Receiver synchros, sometimes referred to as synchro motors, followers, or repeaters, are similar electrically to transmitter synchros. The rotor of the receiver synchro follows in response to the stator voltages generated in the transmitter synchro. Mechanically, a receiver synchro differs from a transmitter synchro in that a damping device is employed in a receiver synchro to prevent overshooting and hunting. Hence, a receiving synchro may be used in place of a transmitting synchro, but a transmitting synchro cannot be used for receiving.

4.2.6.3 Control Transformer Synchro

A control transformer synchro is similar to a receiver synchro except that it is incapable of exerting torque. A control transformer is used where the rotor is required to generate a voltage only. This rotor voltage is known as an error signal. Since the rotor voltage is intended to be fed to a servo amplifier (high impedance input), the winding is many turns of very fine wire, to produce a high impedance. During normal operation, the rotor of the control transformer synchro is nulled when its angular position matches that of the transmitting synchro. Control transformer synchros are used in conjunction with servo systems where the rotor is mechanically positioned to a null.

4.2.6.4 Synchros, Failure Modes and Symptoms

There are three major categories of problems associated with synchros: first, those problems or failures that directly involve the synchro itself; second, those problems associated with wiring and connections; and third, problems associated with electrical zeroing and mechanical alignment.

Detailed descriptive information regarding synchro problems, symptoms, and corrective actions is contained in MIL-HDBK-225.

Failure modes directly associated with the various types of synchros used in the wind measuring and indicating equipment include the following: defective bearings that are either seized or exhibit high friction, a binding or seized inertia damper (receiver synchros only), an open or shorted rotor winding, an open or shorted stator winding, and defective brushes or slip rings.

Symptoms relating to defective bearings or a binding inertia damper involve seizure or sluggishness of response by the synchro.

Symptoms resulting from an open or shorted rotor or open or shorted stator windings are as follows:

Failure Mode	Symptom
Transmitter rotor open	Receiver rotor turns same direction in an erratic manner and overheats.
Receiver rotor open	Receiver rotor turns same direction in an erratic manner and transmitter overheats.
Transmitter rotor shorted	Receiver rotor turns same direction, but plus or minus 90° out of alignment and overheats.
Receiver rotor shorted	Receiver rotor turns same direction, but plus or minus 90° out of alignment and transmitter overheats.
Stator circuit S1 and S2 shorted	When transmitter is at 120° or 300°, receiver indication reads correctly, but when the transmitter is between 340° and 80°, or between 160° and 260°, the overload indicator lights, the synchros overheat and hum, and the receiver stays on 120° or 300°, or swings suddenly from one point to the other.
Stator circuit S2 and S3 shorted	When transmitter is at 60° or 240°, receiver indication reads correctly, but when the transmitter is between 280° and 20° or between 100° and 200°, the overload

(continued)

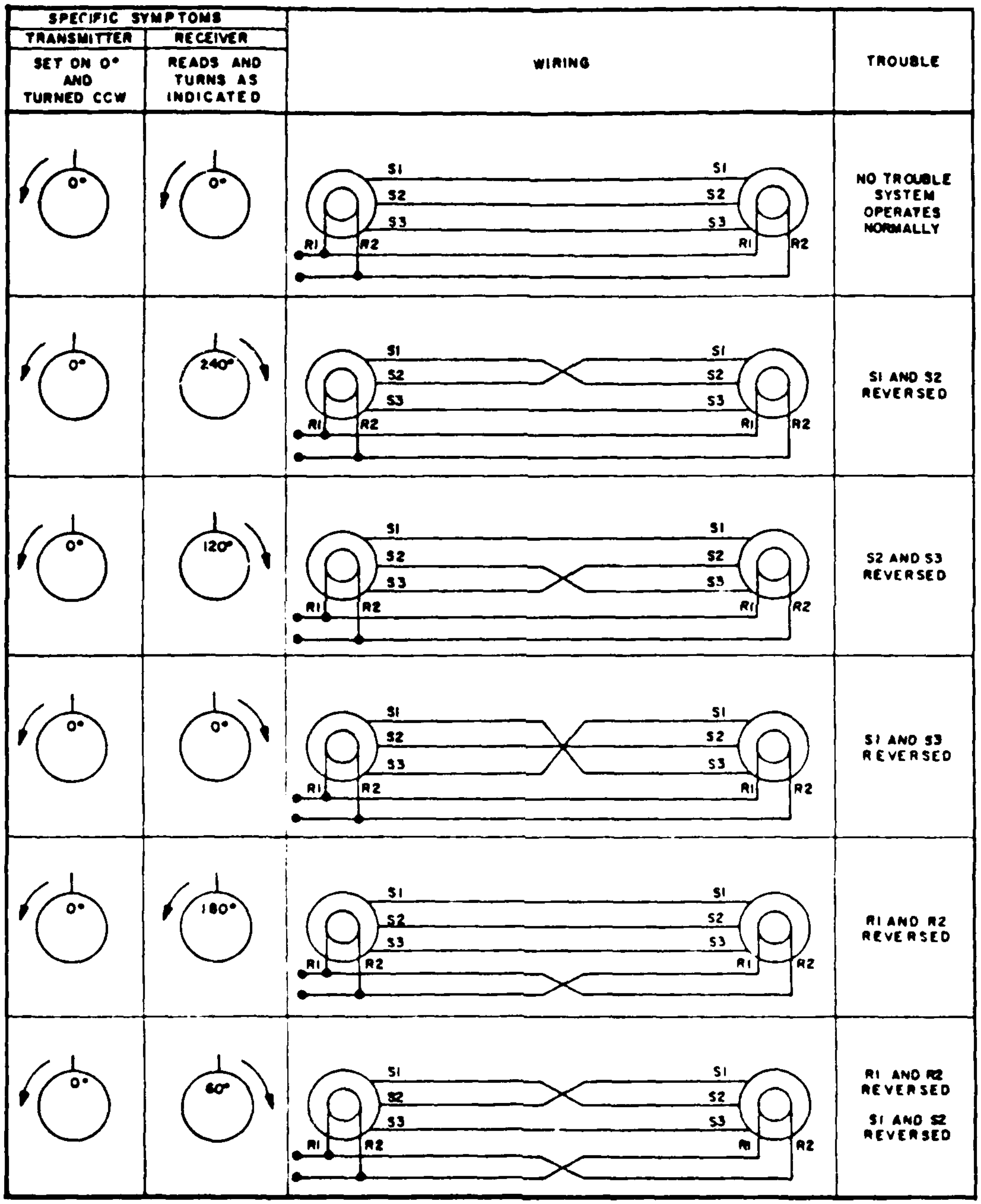
Failure Mode	Symptom
Stator circuit S2 and S3 shorted (continued)	indicator lights, the synchros overheat and hum, and the receiver stays on 60° or 240°, or swings suddenly from one point to the other.
Stator circuit S1 and S3 shorted	When transmitter is at 0° or 180°, receiver indication reads correctly, but when the transmitter is between 40° and 140° or between 220° and 320°, the overload indicator lights, the synchros overheat and hum, and the receiver stays on 0° or 180°, or swings suddenly from one point to the other.
Stator circuit S1 open	When transmitter is at 150° or 330°, receiver reverses or stalls and overload indicator lights. When transmitter is at 0°, the receiver moves between 300° and 0° in an erratic manner.
Stator circuit S2 open	When transmitter is at 90° or 270°, receiver reverses or stalls and overload indicator lights. When transmitter is at 0°, receiver moves to 0° or 180° with normal torque.
Stator circuit S3 open	When transmitter is at 30° or 210°, receiver reverses or stalls and overload indicator lights. When transmitter is at 90°, receiver moves between 0° and 60° in an erratic manner.

Symptoms relating to defective brushes or slip rings involve open or lost electrical contact with the rotor winding. The resulting symptoms are the same as those indicated for an open receiver synchro rotor or an open transmitter synchro rotor as shown above.

Symptoms associated with wiring or connection problems are shown in Figure 3.

Problems and related symptoms associated with electrical zeroing and mechanical alignment are discussed in the following paragraphs.

In any synchro circuit, it is vital that the synchros be electrically zeroed and mechanically aligned and secured. Zeroing and aligning a synchr is required for accurate system operation and unit or assembly interchangeability. Electrical zeroing procedures for synchros are well defined and detailed in MIL-HDBK-225. However, proper electrical zeroing is meaningless if the attaching hardware that ensures mechanical alignment is defective or improperly secured. Defective or improperly secured hardware is one of the primary failure modes recorded against synchros in the wind measuring and indicating system. Loose attachment screws permit the



(continued)

Figure 3. SYNCHRO WIRING AND CONNECTION PROBLEMS

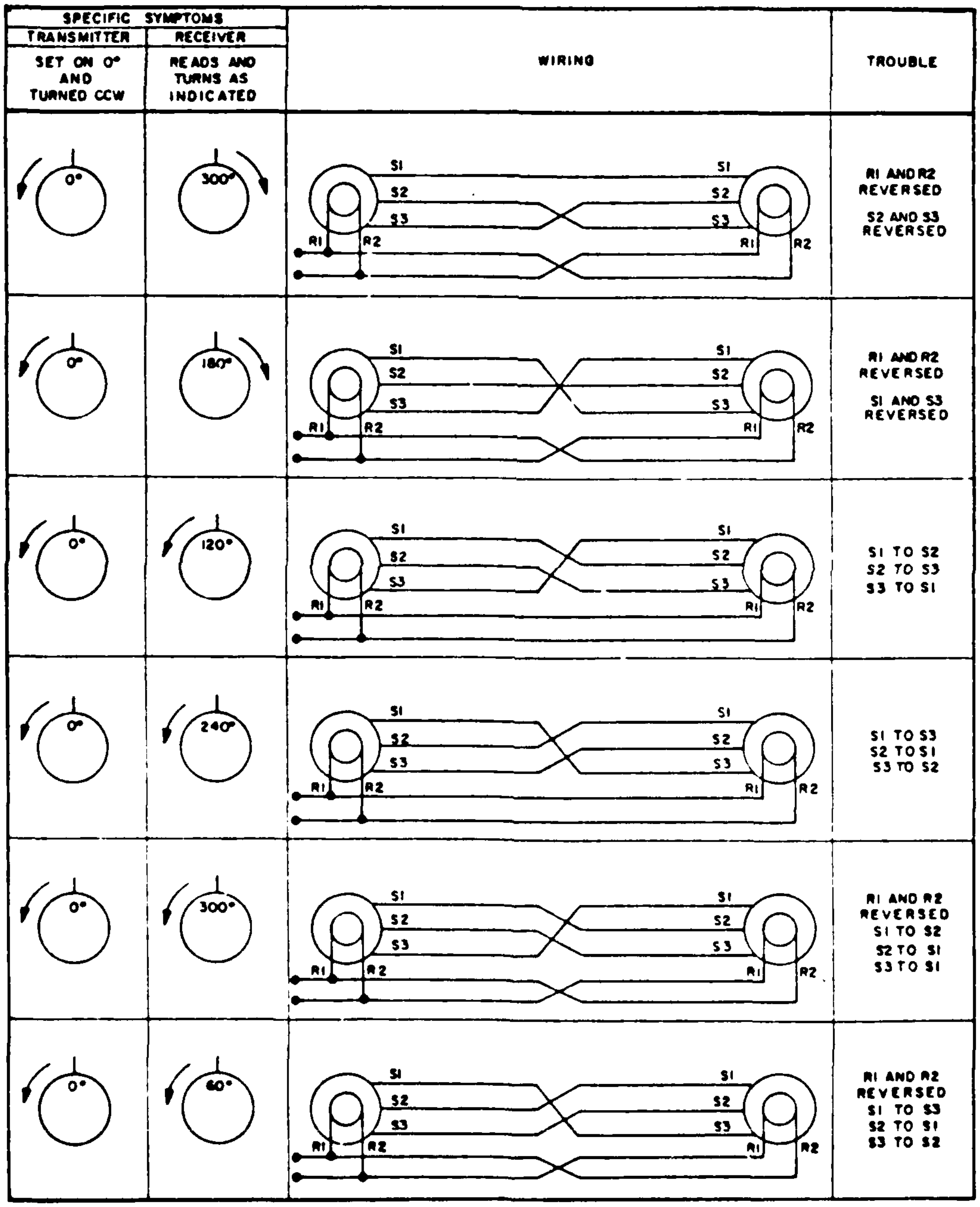


Figure 3. (continued)

synchro housing to rotate, and loose and damaged locking devices (particularly locking drive washers used as a gear retainer and driver) permit relative motion between the synchro rotor shaft and gear.

A locking drive washer is used in mounting a gear on a synchro rotor shaft to eliminate backlash or slippage between the shaft and gear. The inner circumference of the washer is splined to fit the synchro shaft. Two tapered drive dogs on the outer circumference of the washer engage holes in the gear with a force-fit. For locking the shaft nut, tabs are provided to be bent around the nut. The drive washers form a positive lock; however, they are not designed to be reused. Any reuse of the drive washers has a high likelihood of failure associated with the drive dogs and locking tabs.

Improper securing of attaching hardware or the use of defective locking devices will permit relative motion of the synchro housing or synchro shaft, either of which results in loss of mechanical alignment and electrical zero.

Many of the synchro failure modes described herein, open or shorted rotor or stator, wiring and connection problems, and loss of mechanical alignment and electrical zero, can result in erroneous and unrecognizable wind indications that affect safety. As a result, synchro failures subject to these problems must be classified as being of level 4 severity.

4.3 FAILURE PROBABILITIES DETERMINATION

During our review of usage data, we derived normalized annual replacement rates for all individual piece/parts making up the system's failure-significant items. For the most part, BRF data were acquired from SPCC, although in several instances alternate sources including manufacturer's data and Failure Rate Data (FARADA) Program information were used. Since component or piece/part replacements are directly associated with equipment failures, it is postulated that the SPCC best replacement factor (BRF) of a given item very closely approximates the failure rate (λ) for the item. Therefore, the BRFs from SPCC and alternate source failure rates were used in deriving the probability of occurrence for each of the failure-significant items identified in Table 1. The probability of occurrence (P_O) was derived as follows:

$$P_O = 1 - P_S$$

where: P_S is the probability of survival

$$P_S = e^{-\lambda t}$$

where: λ equals the failure rate and t is time, or 1 year in all instances for this analysis

Since: $BRF = \lambda$, and

$t = 1$

$$P_o = 1 - e^{-BRF}$$

Many of the failure-significant items listed in Table 1 contain multiple piece/parts. An estimate of the overall failure rate for the item consists of determining the sum of the indivudal BRFs. This procedure is adequate in many instances; however, when attempting to determine the failure rate for a complex mechanical assembly, one of the fallacies of using basic BRFs becomes apparent -- the problem of dealing with multiple and secondary failures. In an attempt to increase the validity of the quantitative portion of this analysis, each complex failure-significant item underwent a design review. On the basis of the reviewer's engineering judgment, a decision was made relating to dominant failures and ambiguities associated with coincident failures. The rationale associated with these decisions is discussed in detail in the appendix. Those failure-significant items that underwent review are identified by footnotes on the BRF/λ index (see Table 1). The footnotes identify the paragraphs in which the rationale is discussed in the appendix.

Once failure probabilities of occurrence were derived for each of the failure-significant items, the items were grouped into four categories based on their probability levels:

Level 1, Very Low - The chance of a failure occurring is no greater than 1 percent.

Level 2, Low - The chance of a failure occurring is greater than 1 percent, but no greater than 10 percent.

Level 3, Medium - The chance of a failure occurring is greater than 10 percent, but no greater than 22 percent.

Level 4, High - The chance of a failure occurring exceeds 22 percent.

A 22 percent (or 0.22) chance of experiencing a failure equates to a normalized annual failure rate of 0.25. This represents the SPCC BRF decision point for placing spares on board ship. Hence, any level 4 failure-significant item consisting of an individual component or piece/part should be provisioned on board ship to accommodate the likelihood of a failure.

Failure-significant items are categorized by their probability of occurrence group in Table 2. Within each level, the individual items are listed in decreasing order of probability of failure. The level of severity is also indicated for each item.

The table shows that none of the failure-significant items (exclusive of units and assemblies) in the high (level 4) or medium (level 3) failure probability groups have a safety impact.

Table 2. CATEGORIZATION OF FAILURE-CRITICAL ITEMS BY PROBABILITY OF OCCURRENCE AND LEVEL OF SEVERITY OF FAILURES

Item	P_o	L_s
Level 4, High P_o		
Transmitter, Type F	0.865	Unit
Transmitter, Type B	0.818	Unit
Detector, Type B	0.812	Unit
Wind Speed Assembly (TTB)	0.798	Assembly
Wind Speed Assembly (TTF)	0.705	Assembly
CW/HW Computer	0.702	Unit
Gear Train, Wind Speed (WS-DTB)	0.611	3
Detector, Type F	0.601	Unit
Integrator Subassembly, Roller-Disc (WS-TTB)	0.590	3
Integrator Subassembly, Roller-Disc (WS-TTF)	0.564	3
Wind Speed Circuit (CHC)	0.496	Circuit
Wind Direction Circuit (CHC)	0.408	Circuit
Wind Direction Assembly (TTB)	0.382	Assembly
Bearings, Vane Shaft (DTB and DTF)	0.356	3
Wind Direction Assembly (TTF)	0.332	Assembly
Relay (WS-TTF)	0.229	3
Level 3, Medium P_o		
Amplifier, Servo (WD-TTB, WD and WS-CHC)	0.219	3
DC Power Supply (CHC)	0.199	3
Motor, Servo, Reversible (WD-TTF)	0.181	3
Gear Train, Servo (WS-DTF)	0.180	3
Motor, Servo, Reversible (WS-TTF)	0.131	3
Motor, Synchronous (WS-TTB)	0.122	3
Motor, Synchronous (WS-TTF)	0.104	3
Indicator, Type F/60	0.103	Unit
Level 2, Low P_o		
Rotor Assembly, Wind Speed (DTB and DTF)	0.095	3
Synchro, CT (WD-TTB, WD and WS CHC)	0.095	4
Potentiometer, Sine-Cosine (CHC)	0.092	4
Electrical Contact/Slip Ring Assembly (DTB and DTF)	0.089	3
Gear Train, Disc Drive (WS-TTB)	0.077	3
Gear Train, Wind Speed (WS-TTF)	0.075	3
Synchro, Transmitter (WD and WS-TTF)	0.075	4
Gear Train, Servo (WD-TTB)	0.058	3
Gear, Spur (WS-TTB)	0.049	3
Synchro, Receiver (WD and WS-IF6)	0.049	2
Potentiometer, Linear (WS-CHC)	0.046	4
Amplifier, Magnetic (WD and WS-TTF)	0.035	3
Connector (DTB, DTF)	0.034	3

(continued)

Table 2. (continued)		
Item	P_o	L_s
Level 2, Low P_o (continued)		
Synchro, Transmitter (WD and WS-TTB)	0.031	4
Gear Train, Servo (WD-TTF, WD and WS-CHC)	0.030	3
Synchro, Transmitter (WD and WS-TTF)	0.029	4
Synchro, Receiver (WS-TTB, WD and WS-DTB)	0.028	4
Synchro, Receiver (WS and WD-DTF)	0.025	4
Motor, Servo, Reversible (WD-TTB, WD and WS-CHC)	0.023	3
Synchro, CT (WD and WS-TTF)	0.021	4
Level 1, Very Low P_o		
Connector (WD and WS-TTB and TTF)	0.010	3
Connector (IF6 and CHI)	0.009	3
Transformer (WD-TTB, WD and WS-CHC)	0.008	3
Gear (WS TTF)	0.006	3
Transformer, Power (CHC)	0.006	3
Vane Assembly (DTB and DTF)	0.003	4
Inductor (WD-TTB, WD and WS-CHC)	0.003	3

CHC - Crosswind/Headwind Computer
CHI - Crosswind/Headwind Indicator
DTB - Detector, Type B
DTF - Detector, Type F
IF6 - Indicator, Type F/60
TTB - Transmitter, Type B
TTF - Transmitter, Type F
WD - Wind Direction Assembly or Circuit
WS - Wind Speed Assembly or Circuit

4.4 CRITICALITY INDEX

The criticality of the failure of a component or piece/part cannot be assessed in terms of reliability (failure rate and probability of occurrence) alone, but must also include its level of severity. Level of severity classifications were established for the wind measuring and indicating system on the basis of the effect of failure on the operation of the system. These classifications are defined in Chapter Three. Severity levels 3 and 4 (major-recognizable, and major-unrecognizable, respectively) are of primary concern, particularly level 4 since those failures can affect safety.

All failure-significant items classified as having a major effect on system operation, where the behavioral characteristics of failure are not easily recognizable, are listed in Table 3 in decreasing probability of occurrence. The table relates the individual items and their failure rate (λ) to the next higher assembly and unit. Also, the sums of the failure rates for the level 4 severity items (λ total) and the related overall assembly failure probability of occurrence (P_O total) are provided. For example, the wind direction assembly (WD) in the Type B transmitter (TTB) has two level 4 severity failure-significant items that contribute 0.131 failures annually, resulting in a 12.3 percent likelihood of experiencing a failure that may not be readily recognizable. Not all failure modes of an item assigned a level 4 severity classification are unrecognizable.

Failure-significant items having a major effect on system operation, but having readily recognizable behavioral characteristics (level 3 severity) are listed in order of descending failure probability in Table 4. The table relates the individual items and their failure rates to the next higher assembly and unit of which they are a part. The individual failure rates are totaled to show their contribution to the failure rate of the higher assemblies and the probability of their failing.

Table 3. LEVEL 4 SEVERITY FAILURE-SIGNIFICANT ITEMS (POTENTIAL SAFETY IMPACT)

Item	P_o	DTB(λ)	DTF(λ)	TTB(λ)		TTF(λ)		CHC(λ)	
				WD	WS	WD	WS	WD	WS
Synchro, Control Transformer	0.095			0.100				0.100	0.100
Potentiometer, Sine-Cosine	0.092							0.096	
Synchro, Transmitter	0.075					0.078	0.078		
Potentiometer, Linear	0.046								0.047
Synchro, Transmitter	0.031			0.031	0.031				
Synchro, Transmitter	0.029					0.029	0.029		
Synchro, Wind Direction	0.028	0.028							
Synchro, Wind Direction	0.025		0.025						
Synchro, Control Transformer	0.021					0.021	0.021		
Vane Assembly	0.003	0.003	0.003						
λ Total		0.031	0.028	0.131	0.131	0.128	0.128	0.196	0.147
P_o Total		0.031	0.028	0.123	0.031	0.120	0.120	0.178	0.137

Table 4. LEVEL 3 SEVERITY FAILURE-SIGNIFICANT ITEMS (NO SAFETY IMPACT)

Item	P_o	DTB(λ)	DTF(λ)	TTB(λ)		TTF(λ)		CHC(λ)	
				WD	WS	WD	WS	WD	WS
Level 4, High Probability									
Gear Train, Wind Speed	0.611	0.944							
Integrator Subassembly, Roller-Disc	0.590				0.892				
Integrator Subassembly, Roller-Disc	0.564						0.830		
Bearings, Vane Shaft	0.356	0.440	0.440						
Relay	0.229						0.260		
Level 3, Medium Probability									
Amplifier, Servo	0.219			0.247				0.247	0.247
DC Power Supply	0.199								0.222
Motor, Servo, Reversible	0.181					0.200			
Gear Train, Wind Speed	0.180		0.199						
Motor, Servo, Reversible	0.131						0.140		
Motor, Synchronous	0.122				0.130				
Motor, Synchronous	0.104						0.110		
Level 2, Low Probability									
Rotor Assembly, Wind Speed	0.095	0.100	0.100						
Slip Ring Assembly	0.089	0.093	0.093						
Gear Train, Disc Drive	0.077				0.080				
Gear Train, Wind Speed	0.075						0.078		
Gear Train, Servo	0.058			0.059					
Gear, Spur	0.049				0.050				
Amplifier, Magnetic	0.035					0.036	0.036		
Connector	0.034	0.035	0.035						

(continued)

Table 4. (continued)

Item	P_o	DTB(λ)	DTF(λ)	TTB(λ)		TTF(λ)		CHC(λ)	
				WD	WS	WD	WS	WD	WS
Gear Train, Servo	0.030					0.030		0.030	0.030
Synchro, Wind Speed	0.028	0.028			0.028				
Synchro, Wind Speed	0.025		0.025						
Motor, Servo Reversible	0.023			0.023				0.023	0.023
Synchro, Control Transformer	0.021						0.021		
Level 1, Very Low Probability									
Connector	0.010			0.010	0.010	0.010	0.010		
Connector	0.009							0.009	0.009
Transformer	0.008			0.008				0.008	0.008
Transformer, Power	0.006								0.006
Gear	0.006						0.006		
Inductor	0.003			0.003				0.003	0.003
λ Total		1.640	0.892	0.350	1.190	0.276	1.491	0.320	0.548
P_o Total		0.806	0.590	0.295	0.696	0.241	0.775	0.274	0.422

CHAPTER FIVE

CONCLUSIONS

On the basis of the functional review of the wind measuring and indicating system design and the effect of the system's outputs on ship operations, it was concluded that failures affecting safety applied primarily to aircraft operations. Safety-impact failures were defined as component or piece/part failures that cause erroneous wind direction and speed indications whose behavioral characteristics cannot be readily identified (e.g., the indicated and actual wind direction are different), and the equipment appears to be operating normally. Malfunctions having a potential effect on safety were classified as level 4 severity (major, unrecognizable failures). A second level of failure consisted of malfunctions of those component and piece/parts which render the system or the affected portion of the system inoperative; however, the failure effects are easily recognizable and appropriate action can be taken to repair the system. Malfunctions of this type, having minor safety ramifications, were classified as level 3 severity (major, recognizable failures).

The results of the analysis identified 10 individual failure-significant items having a potential safety impact (level 4 severity). These individual items and the units comprising them were shown in Table 3, together with their normalized annual failure rate and probability of occurrence. All of the identified items have failure modes that will provide erroneous wind indications that are not readily recognizable and give the appearance that the system is functioning normally. Failures affecting safety involve primarily synchros and analog computational devices whose failure frequently results in loss of mechanical or electrical alignment or wiring problems leaving an output signal still present, but in error.

An additional 31 failure-significant items (level 3 severity) were identified that can degrade or render the system inoperative (see Table 4); however, these failures are easily recognizable and are considered not to affect safety.

The 10 individual failure-significant items having a safety impact account for 17 applications, since 6 of the items have multiple applications. The same situation exists for the 31 level-3 severity-failure-significant items that account for 51 applications.

APPENDIX

RATIONALE FOR DEVELOPING FAILURE RATE ESTIMATES FOR SELECTED ITEMS OF THE WIND MEASURING AND INDICATING SYSTEM

Selected failure-significant items making up the wind measuring and indicating system contain multiple piece/parts whose individual replacement rates can be used to estimate the failure rate of the overall item. In some instances a reasonable estimate of the failure rate is represented simply by the sum of the individual replacement rates or BRFs. However, when attempting to develop a failure rate estimate for a complex mechanical assembly, consideration must be given to multiple or coincident failure situations (e.g., failure of one gear in a reduction gear train can cause secondary failure of all the intermeshing gears). To accommodate this multiple failure situation within complex mechanical assemblies, the design was reviewed and the item was divided, as required, into groups of components whose failures are interdependent. These groups are referred to as interdependent failure groups. Engineering judgment was used to identify dominant piece/parts whose replacement rate would represent the group failure rate. The intent of the approach was to provide a more realistic result from simply using the sum of the individual replacement rates or BRFs. The rationale used in making these determinations, for items footnoted in Table 1, is discussed in this appendix. Footnote 1 in Table 1 is discussed in Section 1, footnote 2 is discussed in Section 2, footnote 3 is discussed in Section 3, etc.

1. GEAR TRAIN, WIND SPEED, DETECTOR, TYPE B

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Shaft, Rotor (-5)*	0.060	
(2)	Gear, Spur (-16)	0.024	0.880
(3)	Bearing, Ball, 2 each (-11)	0.880	
(4)	Gear Assembly (-70)	0.030	0.030
(5)	Shaft, Pinion (-69)	0.020	0.020
(6)	Gear, Spur (-17)	0.014	0.014
		Total	0.944

*Dash numbers in parentheses are the item identification numbers found on the respective engineering drawings.

Items 1, 2, and 3 form an interdependent failure group whose individual BRFs are overshadowed by a very high replacement rate for the bearings that support the rotor shaft. Engineering judgment suggests that the failure of a rotor shaft or spur gear will most likely be accompanied by bearing replacement, either because of an impending bearing failure, or on a preventive basis. Therefore, the bearing replacement rate will be dominant, including consideration of multiple failures. As a result, we postulate that the replacement rate for the bearings will be the failure rate (λ) for the group. The basic BRFs for the remaining items are included individually with the overall sum and provided as an estimate of the wind speed gear train's normalized annual failure rate.

2. ELECTRICAL CONTACT/SLIP RING ASSEMBLY, DETECTOR, TYPE B AND TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Contact Assembly (-56, -63)	0.054	0.054
(2)	Rings, Collector, 6 each	0.036	0.039
(3)	Washer, Insulating, 5 each	0.039	
		Total	0.093

Items 2 and 3 form an interdependent failure group of two individual parts types whose failure and subsequent corrective maintenance actions are interdependent; i.e., failure of a collector ring will generally involve replacement of at least one, and sometimes two of the adjacent insulators. It is therefore postulated that the slightly higher demand rate for the insulator washers accommodate a multiple failure, or multiple replacement, and the dominant BRF for the insulator will be the failure rate of the slip ring assembly. Adding the contact assembly's BRF to that of the slip ring yields an estimate of the electrical contact/slip ring assembly's normalized annual failure rate.

3. BEARINGS, VANE SHAFT, DETECTOR, TYPE B AND TYPE F

The vane shaft of the Type B and Type F detectors is supported by an upper and lower bearing. The lower bearing (BRF = 0.440) requires replacement approximately twice as frequently as the upper bearing (BRF = 0.250). A worst-case failure rate would be the sum of the two bearing replacement factors (0.690); however, this does not take into consideration the fact that when the upper bearing does fail, the lower bearing will most likely be replaced, either because of a failure, or on a preventive basis. A more realistic estimate of the failure rate for the vane shaft bearings is based on the postulation that the replacement rate of the lower bearing will be dominant and include the multiple failure case. Therefore, the normalized annual failure rate is 0.440.

4. GEAR TRAIN, WIND SPEED, DETECTOR, TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Shaft, Rotor (-7)	0.073	
(2)	Gear, Spur (-16)	0.038	0.090
(3)	Bearing, Ball, 2 each (-90)	0.090	
(4)	Gear Assembly (-46)	0.029	
(5)	Shaft, Pinion (-45)	0.020	0.086
(6)	Bearing, Ball, 2 each (-12)	0.086	
(7)	Gear, Spur (-17)	0.023	0.023
		Total	0.199

Items 1, 2, and 3 and items 4, 5, and 6 form two similar interdependent failure groups. In both cases the dominant failure is the bearings supporting the shaft and gear. Thus, it is postulated that the higher demand rate for the bearings, in both cases, represents the normalized annual failure rate for the individual groups.

5. AMPLIFIER, SERVO

The failure rate for the servo amplifier was estimated on the basis of the sum of the BRFs for the individual piece/parts (see below):

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Transistor (1133548), 4 each	0.216	0.216
(2)	Diode (1132837), 2 each	0.012	0.012
(3)	Resistor, Fixed (RC20GF122K)	0.005	0.005
(4)	Resistor, Fixed (RC20GF470K)	0.007	0.007
(5)	Resistor, Fixed (1133549)	0.007	0.007
		Total	0.247

6. GEAR TRAIN, WIND DIRECTION, TRANSMITTER, TYPE B

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear (-216)	0.030	0.030
(2)	Gear Assembly (-215)	0.030	
(3)	Gear (-220)	0.029	0.029
		Total	0.059

The wind direction gear train in the Type B transmitter forms an interdependent failure group in which two individual gears (items 1 and 3) intermesh with a duplex idler gear assembly (item 2). Failure of items 1 or 3 will generally affect item 2. As a result, the sum of the three

BRFs for the individual gears would yield an unrealistically high estimate of the gear train's failure rate. However, since the duplex idler gear is common to both of the other two gears, it may be assumed that the failure rate of the idler will be accommodated by the sum of the individual failure rates of the two adjacent gears. Hence, the normalized annual failure rate for the gear train is estimated to be 0.059.

7. INTEGRATOR SUBASSEMBLY, WIND SPEED, TRANSMITTER, TYPE B

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Cear Assembly (-22)	0.049	0.049
(2)	Gear, Duplex (-70)	0.036	
(3)	Shaft Assembly (-30)	0.092	0.092
(4)	Roller, Disc Drive	0.190	0.190
(5)	Disc, Driving, 2 each (-58)	0.320	
(6)	Spring (-56)	0.043	
(7)	Bearing, Ball (-61)	0.020	0.320
(8)	Retainer (-60)	0.027	
(9)	Gear, 2 each (-62)	0.053	
(10)	Gear Assembly (-37)	0.220	0.220
(11)	Shaft (-36)	0.065	
(12)	Switch, Limit (-11)	0.021	0.021
		Total	0.892

Items 1, 2, and 3 constitute the wind speed input gear train and shaft assembly for the integrator. Item 2, a duplex gear, intermeshes with gear 1 and the spiral gear end of the shaft assembly (3). Failure of items 1 or 3 will affect item 2. Since the duplex gear is common to both adjacent gears (items 1 and 3), it may be assumed that the failure rate of the duplex gear will be accommodated by the sum of the two adjacent gears.

Items 5 through 8 form the disc mechanism interdependent failure group. The dominant piece/part failure rate of the mechanism is associated with the drive discs; it is virtually an order of magnitude greater than the rate for any other component. Engineering judgment suggests that failure of any of the other components making up the mechanism (bearings, retainer, and spring) will be accompanied by an impending failure of the drive discs. Hence, the failure rate of the drive discs is assumed to accommodate multiple failures and represents the failure rate of the disc drive mechanism.

Items 9, 10, and 11 constitute an interdependent failure group of the internal disc drive gear train. Item 10, a duplex drive gear, intermeshes with items 9 and 11 and is the dominant failure component in the gear train by a significant margin. Its failure rate is postulated to accommodate the multiple failure case and represents the overall ambiguity group.

BRFs for the remaining items are included with the sum of the failure rates of interdependent failure groups to provide an estimate of the integrator's normalized annual failure rate.

8. GEAR TRAIN, SYNCHRONOUS MOTOR

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear, Spur	0.057	0.057
(2)	Gear, Idler, Duplex (-69)	0.094	
(3)	Gear (-63)	0.110	0.110
(4)	Shaft (-67)	0.020	0.020
(5)	Gear (-65)	0.300	0.300 (0.080)*
		Total	0.487 (0.267)*

The synchronous motor gear train in the wind speed assembly of the Type B transmitter provides the constant speed input to the integrator's disc mechanism. Item 2, a duplex idler gear, intermeshes with two adjacent gears (items 1 and 3). Failure of items 1 or 3 will affect item 2. Since the duplex gear is common to both adjacent gears (items 1 and 3), it may be assumed that the failure rate of the duplex gear will be accommodated by the sum of the two adjacent gears.

The basic BRFs for the remaining two items are included with items 1 and 3 to provide an estimate of the gear train's failure rate.

The gear identified as item 5, with a BRF of 0.300, intermeshes with a gear assembly internal to the integrator (see Section 7, item 10), which has a replacement rate of 0.220. Engineering judgment indicates that these two gears experience coincident failures nearly three-fourths of the time. Although the individual replacement rates must be acknowledged for independent consideration of the synchronous motor gear train and integrator subassembly, the degree of failure interdependency must be considered in any determination of a failure rate for the overall wind speed assembly. The independent failure rate of the gear (representing its contribution to the overall failure rate of the wind speed assembly) is estimated to be $0.300 - 0.220 \cong 0.080$.

9. GEAR TRAIN, WIND DIRECTION, TRANSMITTER, TYPE F

The wind direction gear train in the Type F transmitter consists of four individual intermeshing gears. The gears each have a BRF of 0.030, and the failure of any single gear will subsequently cause secondary failure of adjacent gears. As a result of this relationship, the normalized annual failure rate of the gear train is estimated to be 0.030 rather than the sum of the four individual BRFs.

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*Independent gear failure rate contribution to the failure rate of the overall wind speed assembly.

10. GEAR TRAIN, WIND SPEED INPUT, TRANSMITTER, TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear	0.009	0.009
(2)	Gear, Duplex	0.017	
(3)	Gear	0.023	0.023
(4)	Gear	0.046	0.046
		Total	0.078

The wind speed gear train provides the wind speed input to the integrator. Item 2, a duplex gear, intermeshes with two adjacent gears (items 1 and 3). Failure of item 1 or 3 will affect item 2. Since the duplex gear is common to both adjacent gears (items 1 and 3), it may be assumed that the failure rate of the duplex gear will be accommodated by the sum of the failure rates of the two adjacent gears.

The basic BRF for the remaining gear is added to items 1 and 3 to provide an estimate of the gear train's normalized annual failure rate.

11. INTEGRATOR SUBASSEMBLY, WIND SPEED, TRANSMITTER, TYPE F

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Gear Assembly (-246)	0.057	0.350
(2)	Shaft Assembly, Roller (-243)	0.350	
(3)	Disc, Driving (-267)	0.320	0.320
(4)	Spring (-266)	0.043	
(5)	Bearing, Ball (-270)	0.020	
(6)	Retainer (-268)	0.027	
(7)	Gear, 2 each (-265)	0.027	0.100
(8)	Gear Assembly (-274)	0.100	
(9)	Gear Assembly (-271)	0.035	
(10)	Gear Spur (-273)	0.018	0.018
(11)	Switch, Limit, Maximum (-239)	0.021	0.021
(12)	Switch, Limit, Minimum (-239)	0.021	0.021
		Total	0.830

Items 1 and 2 constitute the integrator's wind speed input gear and shaft assembly. Any failure of the input gear assembly will affect the shaft assembly or mating gear in the wind speed input gear train external to the integrator. As a result, the shaft assembly will exhibit the dominant failure rate and accommodate failure of the gear assembly.

Items 3 through 6 form an interdependent failure group representing the disc mechanism identical to that in the Type B integrator. The rationale for estimating the disc mechanism's normalized annual failure rate is given in Section 7.

Items 7, 8, and 9 constitute an interdependent failure group of the integrator's internal disc drive gear train. Item 8 intermeshes with the two other gears (items 7 and 9) and is the dominant failure component. Its failure rate is postulated to accommodate the multiple failure case and, therefore, represents the group.

The basic BRFs for the remaining piece/parts are included with the estimated failure rates for the interdependent failure groups and combine to yield an overall estimate of the Type F integrator subassembly's failure rate.

12. DC POWER SUPPLY, CROSSWIND/HEADWIND COMPUTER

The failure rate for the dc power supply was estimated to be the sum of the BRFs for the individual piece/parts (see below):

	Item	BRF_{basic}	$\lambda_{estimated}$
(1)	Transistor 1141924	0.041	0.041
(2)	Transistor 1137227	0.040	0.040
(3)	Transistor 1137187	0.008	0.008
(4)	Diode 1N538, 4 each	0.012	0.012
(5)	Diode 1136792-3	0.014	0.014
(6)	Diode 1136605, 4 each	0.028	0.028
(7)	Resistor, WW RW59V271	0.017	0.017
(8)	Resistor, Vari RA10LASD1b1A	0.006	0.006
(9)	Resistor, WW RW59V501	0.007	0.007
(10)	Resistor, Fixed RC20GF395J	0.009	0.009
(11)	Resistor, Fixed RC20GF681J	0.007	0.007
(12)	Resistor, Fixed RC20GF3R9J	0.007	0.007
(13)	Capacitor 1136779	0.011	0.011
(14)	Thermistor	0.012	0.012
(15)	Thermistor	0.003	0.003
		Total	0.222