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MILITARY STANDARD

ON-AIRCRAFT, FAULT DIAGNOSIS, SUB-SYSTEMS, ANALYSIS/SYNTHESIS OF

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DEPARTMENT OF DEFENSE
Wash DC 20301

ON-AIRCRAFT, FAULT DIAGNOSIS, SUBSYSTEMS, ANALYSIS/SYNTHESIS OF

MIL-STD-1591

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3. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to Rome Air Development Center/RBRD, Griffiss Air Force Base, New York 13441, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

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1. SCOPE

1.1 Purpose - This standard establishes uniform criteria for conducting trade studies to determine the optimal design for an on-aircraft fault diagnosis/isolation system, hereafter referred to as the On-Board Built-In Test System (OBBIT).

1.2 Application - This standard is applicable to Department of Defense procurements which include the development of on-aircraft fault diagnosis/isolation systems where a selection can be made between such alternatives as central computer controlled on-board centrally polled built-in test equipment (BITE), decentralized BITE, detached Aerospace Ground Equipment (AGE), etc., or combinations of the preceding. The fault diagnosis/isolation systems of interest are those used to diagnose/isolate faults at the flight line (organizational) level of maintenance.

2. REFERENCED DOCUMENTS

2.1 The following documents of the issue in effect on the date for invitation for bids or requests for proposal form a part of this standard to the extent specified herein (see 6.0).

Publications:

RADC-TR-69-140, Test Instrumentation Requirements and Techniques for Advanced Systems.

RADC-TR-71-281, Design of Integral Sensor Test System.

RADC-TR-74-308, Maintainability Engineering Design Notebook, Revision II, and Cost of Maintainability.

(Copies of publications required in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

3. DEFINITIONS AND ABBREVIATIONS

3.1 Line Replaceable Unit (LRU) - A Line Replaceable Unit, generally modular in form, designed to facilitate an on-line remove and replace maintenance concept. It may include smaller modules, such as circuit cards, within it to facilitate off-line replacement or it can itself be the lowest level of replacement such as a circuit card.

3.2 Primary System - The equipment essential to the performance of the basic mission as distinguished from equipment performing a test or monitor function.

3.3 On-Aircraft - An operation performed on the aircraft.

3.4 Off-Aircraft - An operation performed in a facility other than the aircraft.

3.5 Sensor - A device designed into the prime equipment LRUs that converts a particular parameter of the prime equipment into a form that can be transmitted external to the equipment.

3.6 Test Point - The point in a prime equipment where a sensor is placed or where test equipment is attached to perform measurements.

3.7 BITE - Built-In Test Equipment.

3.8 FMEA - Failure Modes and Effects Analysis.

3.9 OBBIT - On-Board-Built-In Test System. The aircraft fault detection/isolation system.

4. GENERAL REQUIREMENTS

4.1 Required Parameters - The contractor shall perform trade studies to determine OBBIT design for most cost-effective maintenance over the life cycle. The studies shall include the following considerations:

a. Contract requirements

b. Failure modes and effects

c. Alternate system configurations

d. Alternate diagnosis/isolation methods

e. Life cycle cost

f. Standardization of hardware and software

4.2 Sequence of Work - The contractor shall analyze the contract requirements to determine the minimum required system capability and the constraints on his design. The contractor shall generate or obtain reliability information and a failure modes and effects analysis from the configuration of the aircraft avionics (the primary system) to be handled by the OBBIT (including alternative configurations of the primary system, if any). This information shall be combined to determine feasible options for the concepts to be used in designing the OBBIT. Necessary degrees of detail regarding the complexity, reliability, design characteristics and costs of each option shall be developed as inputs to the preceding analysis. These shall be developed by the contractor to the level required for each option. If desired a modified form of the design synthesis procedure (see 5.3) may be used for this purpose. A cost analysis shall be performed on the options to determine their life cycle costs, and the most cost effective option selected. The reliability and FMEA data shall then be used with the selected option to synthesize a detailed design for the OBBIT, implementing the selected concept in the most cost-effective manner.

4.3 Sensitivity Analysis - All analyses performed will be subjected to a sensitivity analysis to determine the effects of possible errors in the input data. The results of sensitivity analysis shall be considered in selecting the final design.

5. DETAIL REQUIREMENTS

5.1 Determination of Conceptual Options - The contractor shall formulate conceptual options for the design of the OBBIT from the following inputs:

a. Contractual requirements

b. Primary system configuration

c. Primary system reliability data

d. Primary system FMEA

5.1.1 Contractual Requirements - The contractual requirements shall be used to:

a. Define design boundaries such as size and weight constraints.

b. Define the maintenance capabilities which the OBBIT shall provide such as:

(1) Time limitations for fault isolation.

(2) Maintenance manhours per flying hour.

(3) Minimum proportion of equipment failures identifiable by OBBIT.

(4) Fault indication requirements.

c. Establish special installation environmental conditions (location, access, temperature, etc.) of the OBBIT.

d. Establish reliability requirements for the OBBIT to meet its mission.

5.1.2 Primary System Configuration - The primary system configuration shall be used to:

a. Determine system(s), subsystem(s) and LRUs to which OBBIT will apply.

b. Define the size and function of the system, subsystem and LRUs.

c. Determine the amenability of the system to various diagnostic concepts.

d. Determine commonality and redundancy within the system.

e. Provide information for reliability and FMEA analysis.

5.1.3 Reliability and FMEA Data - Reliability and FMEA data on the primary system shall be used to:

a. Determine the relative frequency of failure of each LRU.

b. Determine the criticality of failures.

c. Determine the effects of failure to:

(1) Establish the difficulty of diagnosis.

(2) Determine possible methods of diagnosis.

5.1.4 Formulation of Options - The information provided by items discussed in paras. 5.1.1 through 5.1.3 shall be used for formulating feasible options for the OBBIT which may include:

a. Test points used in conjunction with manual AGE such as voltmeters, oscilloscopes, etc.

b. Integral fault sensors which detect a failure and transmit a signal to a test point.

c. Indicators measuring key parameters or the output of integral fault sensors which must be monitored and interpreted by the operator (e.g., panel meters).

d. Go/no-go indicators, such as lamps, which indicate a fault in a designated location based on the levels of system signals or integral fault sensors.

e. Computer driven interrogation of the system with results deployed on go/no-go indicators, using a simple computer which shall be provided with the OBBIT.

f. Computer driven system diagnosis, using a special fault computer or a general purpose computer which shall be included in the primary system with results displayed on cathode ray tubes, teletype printers, etc. The display shall be capable of programming and indicating the specific failed item to be replaced.

g. Computer diagnostic routines which effect self-repair by switching in redundant units or programming system operation around faults.

h. Any combination of the above.

5.1.5 Cost Analysis Data - Analysis shall be performed to provide estimation of cost relative to the implementation of each OBBIT design alternative. Cost estimates shall be developed relative to development, production and support costs (manpower and hardware associated) for each design alternative to the extent required for exercise of the cost model described in para. 5.2.1.2.

5.1.6 Government Provided Data - The government will provide the contractor basic supporting information and data necessary for the computation of parameters, quantities, and terms contained in, and necessary to the exercise of, analysis/synthesis models and procedures, and which are outside the control of the contractor. Such information and data will represent the best estimates available at the time for the purposes of analysis/synthesis. Examples of such information and data include, expected flying hours per year and cost per maintenance manhour.

5.2 Selection of Optimum Conceptual Option - The most cost-effective option shall be selected, from the conceptual options formulated for the design of the OBBIT. Determination of the most cost-effective option shall be required by use of the model specified herein (para. 5.2.1 and subparagraphs). However, other models which consider all the appropriate variables of the model presented herein (or any other appropriate variables) may be used subject to approval of the procuring activity.

5.2.1 Selection Models - The following paragraphs provide a cost model for evaluating OBBIT options. A model is also provided for computing maintenance manhour requirements, since this is a parameter of interest and one which may be a constraint.

5.2.1.1 Terms Used in the Models:

a. T_{PM} = Flying hours between preventive maintenance for OBBIT.

b. T = Flying hours/unit OBBIT/year.

c. C_D = Development cost of OBBIT.

d. C_p = Average production cost of OBBIT (the average cost of a single unit).

e. C_{aux}= Total cost of any auxiliary test or maintenance equipment, external to OBBIT, required to support or complete fundamental OBBIT tasks. (For example, a supplemental piece of test equipment necessary to complete a fault isolation task.)

f. C_{maux} = Cost per year of maintaining all required auxiliary test or maintenance equipment.

g. N = Number of units of OBBIT or units containing OBBIT produced.

h. N_F = Average number of units of OBBIT or units containing OBBIT in field use at any time.

i. MMH_i = Average maintenance manhours required for initial fault isolation/detection by OBBIT. (NOTE: If fault isolation/detection is fully automatic MMH_i = 0.)

j. A_i = Average number of LRUs to which the OBBIT initially isolates. (This may be derived in a variety of ways depending on the fault isolation/diagnostics subsystem characteristics and the LRU partitioning design.) A suitable formulation determining the necessary or target value of A_i shall be developed by the contractor taking into account relative frequency of LRU failure, maintenance time constraints and considerations, fault isolation procedures and other characteristics considered during predesign analysis, subject to the approval of the Procuring Activity.

k. MMH_{sa_i} or MMH_s = Average maintenance manhours as required for secondary isolation (to determine which of the A_i LRUs is the malfunctioning unit). This value can be calculated by various means, depending on the provisions for troubleshooting/diagnosis provided:

(1) If isolation is to be done by randomly testing or replacing the A_i LRUs:

$$MMH_{sa_i} = \frac{A_i}{2} MMH_{sa}$$

where

MMH_{sa} = Average maintenance manhours required to determine that a given LRU is operating or failed.

(2) If a sequential troubleshooting guide is provided, the value of MMH_{sa_i} shall be calculated taking into account the average manhours required to take each troubleshooting action, the relative probabilities of failure of each of the A_i LRUs (the latter may be calculated as $\frac{\lambda_j}{\sum_{i=1}^{A_i} \lambda_i}$ where λ_j = the failure rate of LRU (j) belonging to A_i) and the troubleshooting sequence.

(3) If the different sets of LRUs of the equipment have different values of A_i a suitable model defining MMH_s the average maintenance manhours to effect secondary isolation (where MMH_s will be substituted for the MMH_{sa_i} factor) shall be developed by the contractor as a function of the troubleshooting procedure, time/manpower estimates, and probability of failure, subject to the approval of the Procuring Activity.

l. When OBBIT is designed to isolate to a unique LRU, MMH_{sa_i} or MMH_s equal 0.

m. MMH_{RP} = Average maintenance manhours required for manual trouble-shooting to isolate to a LRU in the event OBBIT does not recognize a failure has occurred.

n. MMH_{PM} = Average maintenance manhours per OBBIT preventive maintenance action (provided PM applicable to OBBIT).

o. λ_I = Failure rate of OBBIT (based on components of OBBIT not needed for prime equipment function).

p. λ_{PE} = Failure rate of prime equipment(s) which OBBIT serves (does not include failure rate of parts belonging uniquely to OBBIT), in failures/flying hour.

q. Z = Number of years unit contemplated to be in service (service life).

r. C_{IFMA} = Average cost/OBBIT failure (material, spares, etc.).

s. C_{IFMP} = Average manhours required to repair an OBBIT failure.

t. P_F = Proportion of prime equipments' faults not detectable by applicable OBBIT.

u. C_{MH} = Cost/maintenance manhour.

v. C_{FD} = Average cost to determine failure has occurred. In some systems the incidence of failure is evident even though OBBIT is incapable of detecting same. For these cases C_{FD} = 0. Taking the other extreme, failure may remain undetected until primary system mission commitment and so cause mission abort or failure. In that case C_{FD} = Estimated Average Cost of mission abort or failure.

5.2.1.2 Cost Model

Cost of any OBBIT alternative =

$$C_D + NC_P + C_{aux} + ZC_{maux} +$$

$$(1-P_F)\left[N_F \lambda_{PE} TZ\ (MMH_i + MMH_s\ )\right]\left[C_{MH}\right] +$$

$$P_F \left[N_F \lambda_{PE} TZ\right] \left[(MMH_{RP})\ (C_{MH}) + C_{FD}\right] +$$

$$N_F \lambda_I TZ \left[C_{IFMA} + C_{IFMP}(C_{MH})\right] +$$

$$\frac{N_F TZ}{T_{PM}}\ (MMH_{PM}) \left[C_{MH}\right]$$

5.2.1.3 Maintenance Manpower Model

Taking into account direct maintenance manhours only, total maintenance manhours =

$$(1-P_F) \left[N_F \lambda_{PE} TZ \quad (MMH_i + MMH_s)\right] + P_F \left[N_F \lambda_{PE} TZ \quad (MMH_{RP})\right] +$$

$$N_F \lambda_I TZC_{IFMP} + \frac{N_F TZ}{T_{PM}} \quad (MMH_{PM})$$

5.2.1.4 False Alarm Rate Considerations - The False Alarm Rate of OBBIT can contribute substantially to the cost of field maintenance manpower, associated with any particular OBBIT design option. An assessment based on historical false alarm rate experience, or engineering judgement, shall be made for each concept considered as an OBBIT option. The results of such an assessment shall be integrated into the cost, and maintenance manpower models provided that there exist significant differences in false alarm rate among design options.

5.3 Procedure for Synthesizing Detailed Design of the Selected OBBIT Concept - The procedure described herein represents a logical quantitative approach to the attainment of a cost-effective design for the OBBIT, taking into account maintenance, maintainability, reliability and cost characteristics, and also provides support cost visibility throughout the design process. Other models may, however, be used subject to approval of the procuring activity.

5.3.1 Predesign Analyses Necessary - Analyses shall be performed to determine constraints relative to the characteristics of the OBBIT subsystem and its parts.

5.3.1.1 Determination of Design Constraints - Analyses shall be performed on the maintenance manhours and the mean-time-to-repair requirement (in cases where only one of these maintainability figures of merit is used as a requirement the analysis shall be performed on it) to determine (X), the maximum permissible number of LRUs that may be isolated by a single set of diagnostics (when a group of two or more LRUs are identified by a given set of diagnostics/test to contain the failed LRU, and final diagnosis shall be made by semi-automatic or manual means which incur time costs). This value shall be used as a guide to define a target value (s) of A_i. In order to accomplish this, the cost in terms of time and manpower required to isolate to a single LRU (given that it is known that one LRU of a group of LRUs is failed) must be predicted, considering the relative failure frequencies and maintainability characteristics of the LRUs in the group. The analysis shall, in addition, determine a value for $(1-P_F)$, the minimum proportion of equipment failures identifiable by the equipment's built-in test (e.g., a minimum of 95% of all equipment faults shall be detectable by the equipment's built-in test capability) consistent with the requirements on mean-time-to-repair and maintenance manhours. This shall be accomplished by consideration of the maintenance manhours or mean-time-to-repair requirements, the costs and manpower required to diagnose an equipment fault in the event a failure was not detected by the built-in test equipment and the relative frequency of occurrence of such failures. The analysis rationale used for the above shall be subject to procuring activity review and approval.

5.3.1.2 Failure Modes and Effects Analysis - A Failure Modes and Effects Analysis shall be performed to determine the types and performance symptoms of failure inherent to the equipment design. This analysis shall be used to determine:

a. The types of fault detection means which are practical.

b. At what points isolation, to LRUs or groups of LRUs, can be implemented (through sets of diagnostic hardware or software).

c. The proportion of faults in each such LRU or group of LRUs detectable by the diagnostics in question.

5.3.1.3 Reliability and Maintainability - Reliability and maintainability analyses (predictions) shall be available down to the LRU level.

5.3.1.4 Cost Information Relative to Fault Detection Implementation - An analysis to provide cost information relative to the implementation of each means of fault detection considered shall be prepared. The cost shall be expressed in terms of production cost, support manhour cost, life cycle cost or cost as defined by the procuring activity (see definition of C_{Ki} in para. 5.3.2.3).

5.3.2 Basis for the Design Procedure - This procedure is based on the concept that a cost-effective OBBIT subsystem should provide a greater degree of capability to isolate those failures which occur most frequently than those that occur less frequently. Further, it assumes that support costs (related to the ramifications of a given set of diagnostics) shall be considered during design. The basic premise for decision is the maximization of the proportion of equipment failures isolated per resource expended. An iterative procedure is used which, after any given amount of automatic diagnostics has been selected for the design, determines the most cost-effective next step and provides insight of the necessary characteristics for the ensuing diagnostic sets of hardware or software.

5.3.2.1 Information to be Provided - The analyses described above shall provide the following information for guidance:

a. The maximum number of LRUs, (X), which can comprise a group of LRUs, isolatable by a given set of diagnostics (for example, a set of diagnostics can indicate that the failed LRU is one of three particular LRUs).

b. The average proportion of faults in each LRU or group of LRUs detectable by the diagnostics in question.

c. The reliability characteristics of each LRU.

d. Information such that the cost of each set of diagnostics can be calculated.

5.3.2.2 Determination of Alternatives -

In each iteration to provide a set of diagnostics (set i), the spectrum of possibilities shall be examined using a family of matrices. Each matrix in the family will present alternative diagnostics for all groups of LRUs which includes a specific LRU (LRU j), where LRU j is any LRU not considered in diagnostic sets selected in previous iterations. Hence, the family of matrices in the first iteration will include a matrix for all LRUs in the primary system and the number of matrices in the family will decrease with each iteration (see para. 5.3.3). The form of each matrix is as follows:

Alternatives for Set i of Diagnostics

Combinations of LRUs including LRU j*	Group Size	Proportion of Failures Detected	Cost
A	N_{Ai}	P_{oAi}	C_{Ai}
B	N_{Bi}	P_{oBi}	C_{Bi}
.	.	.	.
.	.	.	.
.	.	.	.
Z	N_{Zi}	P_{oZi}	C_{Zi}

*[Each combination (A, B,...Z) contains from 1 to X LRUs including LRU j.]

5.3.2.3 Explanation of Terms Used:

a. S = Total number of LRUs in equipment.

b. N_{Ki} = Total number of LRUs in group K of LRUs under consideration to be covered by the ith set of diagnostics (where group defines a collection of one or more LRUs wherein the event of failure in one of the LRUs, isolation is made to the collection, rather than individual LRU).

c. λ_η = Failure rate of the ηth LRU.

d. X = Maximum number of LRUs contained in a group (determined from previous analyses).

e. P_K = A priori probability that a LRU in group K has failed, given an equipment failure.

f. P_{oKi} = Proportion of faults in group K of LRUs under consideration to be detectable by the ith set of diagnostics.

$$P_K = \frac{\sum_{\eta=1}^{N_{Ki}} \lambda_\eta}{\sum_{n=1}^{S} \lambda_\eta}$$

g. $(1-P_F)$ = Target value for proportion of faults in entire equipment detectable by automatic diagnostics/isolation/test subsystem (developed from analyses in paragraph 1.2).

$$\sum_{i=1}^{M} P_{oi} \, P_i = (1-P_F)$$

P_i = A priori probability that an LRU in the group covered by the ith set of diagnostics has failed, given an equipment failure.

P_{oi} = Proportion of faults in the group of LRUs detectable by the ith set of diagnostics.

Where M = Estimated number of groups of LRUs (sets of diagnostics) in equipment.

h. C_{Ki} = Cost of using group K of LRUs as the group of LRUs to be associated with the ith set of diagnostics. This can be expressed as:

(1) Hardware cost of implementing the ith set of diagnostics over and above that which has already been expended to implement the first (i-1) sets of diagnostics (the ith set of diagnostics might, for example, need a test circuit which has already been included in one of the other sets of diagnostics implemented. The cost of that circuit would not be included in C_{Ki}). (NOTE: C_{Ki} will also exclude costs associated with the use of existing circuitry, or software necessary for basic equipment operation and function.)

(2) Cost in organizational maintenance manhours/year for diagnostics for that portion of a single system which OBBIT serves. In that case

$$C_{Ki} = \frac{P_K T}{MTBF}\left[P_{oKi}\,\overline{MMH}_{D/N_{Ki}} + (1-P_{oKi})\,\overline{MMH}_{D/S}\right]$$

where: T = Flying hours/year/prime system (equipment).

MTBF = Mean time between failure of prime system (equipment).

$\overline{MMH}_{D/N_{Ki}}$ = Average maintenance manhours to isolate (by semi-automatic or manual means) to the failed LRU, given failure is automatically isolated to a group of LRUs of size N_{Ki}, by set of diagnostics/test, i.

$\overline{MMH}_{D/S}$ = Average maintenance manhours to isolate (by semi-automatic or manual means) to the failed LRU, given automatic diagnostics are inoperative or are incapable of isolation to a given group of LRUs.

(3) Cost in logistics and support resources necessary to the maintenance of the OBBIT itself.

(4) Any combination of the above (translated into dollars).

5.3.3 Procedure - Develop matrices of alternatives as discussed in para. 5.3.3.2 for the first diagnostic set. Consider all possible alternatives for the LRUs. For each determine the following numeric for i=1.

$$\frac{P_K P_{oKi}}{C_{Ki}} = \frac{\text{Proportion of faults isolated}}{\text{Resource cost}}$$

Choose the alternative which maximizes this numeric. Develop new matrices for the second diagnostic set, not including combinations which contain any of the LRUs which comprised the group of LRUs diagnosable through diagnostic set 1. Repeat the above for the 2nd diagnostic set, i=2. Continue repeating for i=3, i=4...i=M, until all LRUs are divided into groups (equal to or less than X LRUs) covered by suitable diagnostics.

Recognizing that a final value of $(1-P_F)$ can result in a number of ways, the following provides guidance as to:

$\overline{P}_{oa/i}$ = Average proportion of faults detectable per remaining unformed groups of LRUs, which must be maintained or bettered in order to meet the P_F target.

$$\overline{P}_{oa/i} = \frac{1-P_F - \sum_{i=1}^{K} P_i P_{oi}}{1 - \frac{\sum_{n=1}^{K} \lambda_r}{\lambda PE}}$$

where: K = Total sets of diagnostics (groups of LRUs) implemented to date.

M = Estimated total sets of diagnostics (groups of LRUs) to be implemented in the equipment.

λ_{PE} = Failure rate of prime equipment which OBBIT serves.

Information relative to the above can serve to decrease the size of the matrices for the (K+1) diagnostic set by eliminating from consideration groups with values of P_{oKi} which are too large. It also serves to indicate if changes or modifications in plans and designs of diagnostic/isolation/test systems are required (for example, values of any P_{oi} may be increased or decreased with attendant cost changes).

The relationship

$$C_i = \frac{P_i T}{MTBF}\left[P_{oi}\,\overline{MMH}_{D/N_i} + (1-P_{oi})\,\overline{MMH}_{D/S}\right]$$

provides step-by-step visibility of the manpower cost attributable to that particular diagnostic set characteristic.

Where: C_i = Operational manpower cost attributable to the ith set of diagnostics.

$\overline{MMH}_{D/N_i}$ = Average maintenance manhours to isolate (by semi-automatic or manual means) to the failed LRU, given failure is automatically isolated to a group of LRUs of size N_i by set of diagnostics/test i.

$\overline{MMH}_{D/S}$ = Average maintenance manhours to isolate (by semi-automatic or manual means) to the failed LRU, given automatic diagnostics/test are inoperative or are incapable of isolation to a given group of LRUs.

6. RADC PUBLICATIONS

The following RADC publications are suggested for use as guidance to determine the optimal design for an On-Aircraft Fault Diagnosis/Isolation System (see Section 2):

RADC-TR-69-140, Test Instrumentation Requirements and Techniques for Advanced Systems.

RADC-TR-71-281, Design of Integral Sensor Test System.

RADC-TR-74-308, Maintainability Engineering Design Notebook, Revision II, and Cost of Maintainability.

7. DATA

When delivery of a System/Cost Effectiveness Program Plan (DD Form 1664, reference DOD DI-S-3569 in the Department of Defense Authorized Data List) is specified by the Contract Data Requirements List (DD Form 1423), the contractor will include in the data item a discussion of his plans for performing the analyses described herein.

Custodians:
Army - AV
Navy - AS
Air Force - 17

Review Activities:
Army -
Navy -
Air Force - 10, 11, 13, 91, 99

Preparing Activity:
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