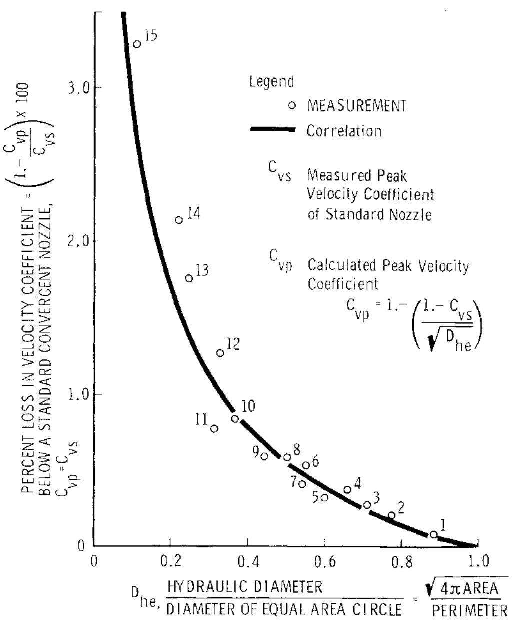

Fig. 2 Effect of hydraulic diameter on convergent nozzle performance.

D_{he} places the emphasis for comparison on the wetted perimeter for the same exit area. For nozzles of noncircular cross section, the internal surfaces are not all scrubbed at the free-stream velocity, and thus the momentum thickness varies over the perimeter. To account for this variation in skin friction and still use the standard round nozzle for a basis of comparison, dimensional analysis will be employed. Reynolds' analogy defines a relation between the skin-friction coefficient C_f and the Stanton number St[3]:

$$C_f/2 = St = Nu/RePr \tag{3}$$

where $Nu = Re^{1-n}Pr^m$.

Thus,

$$C_f/2 = Re^{-n}Pr^{m-1} \tag{4}$$

Since the boundary layer is to be evaluated at the nozzle throat for the same fluid flow conditions, then the skin friction varies only with the characteristic dimension term in the Reynolds number Re to some power n. The characteristic dimension used in this type of correlation is the hydraulic diameter D_h. Then the exponent n depends upon the turbulence level of the boundary layer. Here n varies from 0.5 for laminar flow to 0.2 for turbulent flow.

If the momentum thickness is assumed to be directly proportional to the local skin-friction coefficient at the nozzle exit, then

$$\theta \alpha C_f \alpha D_{he}^{-n} \tag{5}$$

The peak velocity coefficient of Eq. (2) is represented in terms of the maximum velocity coefficient $c_{vs} = 1$ and 4 with $1 = c_{vs}/(D_{he})^n$. Thus,

$$c_{vp} = 1 - [(1 - c_{vs})/(D_{he})^n] \tag{6}$$

The exponent n is found from the correlation to be 0.5.

As the nozzle perimeter is increased, the performance of nozzles with equivalent hydraulic diameters less than 0.3 (Fig. 1) falls below the correlation. This performance loss can be attributed to significant base pressure drag caused by an inability to ventilate this base region properly.

The data are presented in Fig. 2 as percent loss in velocity coefficient below the standard nozzle. This places the data in a comparative frame of reference and eliminates the universal problem of absolute magnitude of the standard nozzle performance. The accuracy of the data as presented in Fig. 2 is within 0.25%, which is the range of the data from the correlation to an equivalent hydraulic diameter of 0.3.

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Using Maintenance Float to Measure the Value of Maintainability and Reliability

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ONE of the problems associated with product design is to measure the value of increased reliability or maintainability; that is, how much more maintainability and reliability to work for, or, conversely, to determine the value of the levels achieved. This note describes an analytic method for doing this quickly and with reasonable accuracy, using the amount of equipment in the "maintenance float" as the criterion.

Maintenance Float as a Measuring Unit

A fleet of trucks, radios, or other devices must not only operate but keep on operating. To support it, some extra equipment is usually made available. Maintenance float is a kind of "revolving fund" of extra equipment. Equipment that fails is replaced by a unit from the float, and the old unit is repaired and returned to the float. It is this feature of replacement and concurrent repair which is unique to the float system. The amount of float required, F, is usually computed from the equipment population Q_0 and the float factor f as $F = Q_0f$. For equipment that has an exponential failure distribution, f is shown[1] to be

$$f = 1 - [e^{-g}(Q_0 - 1)/Q_0] \tag{1}$$

where g is the ratio of mean time to repair (MTTR) to the mean time between failures (MTBF). This expression has been plotted in Fig. 1 for several representative populations. In army practice, f ranges from 0.03 to 0.35.

Equation (1) can be used to show how much improvements in maintainability and reliability reduce the maintenance

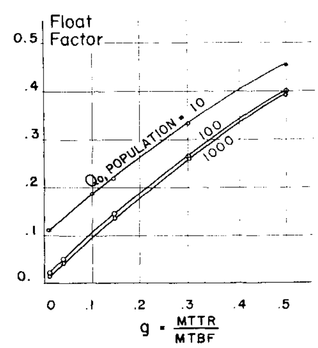

Fig. 1 Maintenance float.

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float. The use of this expression for evaluating equipment changes is made easier by replotting it as in Figs. 2 and 3. Since g is a ratio, the coordinates may be expressed as minutes, days, or any other consistent units. Assume for some device that MTTR = 30 hr, MTBF = 200 hr, and unit cost = \$5000; then, in Fig. 2, the float factor at point A is $f = 0.15$. If 1000 items are needed, another 150 must be purchased for the float; the basic stock will cost \$5,000,000 and the float another \$750,000. Suppose now that there is a need to reduce the cost of support, with demands that the MTTR be reduced to 8 hr (point B, Fig. 2). With this improvement, $f = 0.05$, and the float needed is reduced by \$500,000, which could then be measured against engineering and related costs.

Suppose, alternatively, that there was a limit on time to do all of the engineering desirable and a limit on changes to the configuration, and the actual results of an improvement program fell at some point D (MTTR 22 hr, MTBF 250 hr). What is this achieved improvement worth? At point D, $f = 0.1$; the float cost has been reduced by \$250,000 relative to point A. The net savings would be this amount less the engineering and other costs. On the next purchase, the gross savings would be fully realized.

One can also use Figs. 2 and 3 to determine whether parts of lower reliability (and thereby lower cost) could represent a preferred solution. Therein lies a basis for evaluating, for example, modular components that might be short-lived but readily installed.

Note that the MTTR is a matter of having parts available, providing ready access to the working area, having trained technicians and diagnostic equipment, tools, and so on; these are the parameters of product design. The MTBF is a function of component design, proper quality control, material selection, and component application. Since f is a function of the ratio g rather than the absolute values of MTTR and MTBF, it is obvious that neither reliability nor maintainability alone is the touchstone of good equipment; an appropriate combination is needed.

As noted earlier, the analytic expression was developed for equipment that follows the exponential failure distribution. That equipment ranges from electronic equipment to fleets of airplanes.[2] It may be applicable to other failure distributions such as the Weibull and Gaussian, and even to tabular data, but this has not yet been examined.

Other Approaches to Evaluating Maintainability and Reliability

In most cases, gains due to improved maintainability and reliability are evaluated in operational units: fewer maintenance hours per flight hour, less down time, more availability, shorter checkouts. The Navy's Integrated Maintenance Management Program (formerly WRAP) is directed toward controlling both maintenance time per flying hour and down time.[3] Similarly, design guidelines for predicting maintenance time are being developed for the Air Force.[4] Methods for improving maintainability are contained in the Navy's Maintainability Design Handbook.[5]

To demonstrate the money value of increased maintainability, alone or in combination with reliability, is a more complex problem, since it involves the logistics behind equipment in the field. The usual approach is to build up a cost picture (parts, operating hours, all types of manuals, tools and equipment, personnel and training costs, etc.) and then to examine it on the basis of possible changes. This was done in Ref. 6, which contains a brief description of the Air Force's experiences with improving a complex electronic system; it brings out the healthy effect of improvements in maintainability and reliability on the maintenance effort, the amount of down time, and the availability. A formal description of a somewhat similar technique prepared for the Navy is set forth in Ref. 7.

Table 1 Float factors

MTTR, hr	MTBF 0.35	1.0	3.0	10.	20.
0.1	0.34	0.18	0.13	0.11	0.10
0.05	0.21	0.15	...	...	...
0.01	0.13	0.11	...	...	...

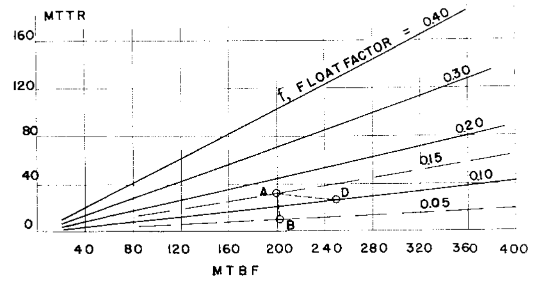

Fig. 2 Maintenance float factors for $Q_0 = 1000$.

Estimating the Validity of the Maintenance Float Approach

It is possible to get some idea of the validity of the maintenance float concept presented in this note by comparing its guidance with the decisions made in an actual case. Reference 6 describes the Air Force's 412L system, which comprises 13 AN/GPA73 subsystems. The author describes the improvement in design reliability from 1959 to 1961, gives some operational figures, and shows that the gains substantially outweigh the cost. He offers three measures: reduction in maintenance costs, the dollar value of operating time recovered from down time, and the improvement of equipment availability. From the article, the following performance data for 1959 can be derived: MTTR = 0.1 hr; MTBF = 0.35 hr. From Fig. 3, for $Q_0 = 10$, Table 1 shows float factors for various possible goals. (The table could also be prepared to show the dollar cost of maintenance float, based on a unit cost of \$30,000,000.) With these figures, the choice of a goal can be related to the amount of savings desired and the practicability of achieving it. In this case, it is probable that an improvement either in repair time or in reliability would require a breakthrough. Furthermore, the figures suggest that a reduction in repair time is not as promising as reliability improvement; a repair time of 0.01 hr is less likely than an MTBF of 3 hr. So, with a little hindsight to help, a reliability improvement program with a 3-hr MTBF goal is selected. The estimated reduction in float costs from \$100,000,000 to \$38,000,000 would justify a substantial amount of work in that direction. The actual results confirm this guidance. The article reports that the system achieved a MTBF of 20 hr at an engineering improvement cost of \$1,460,000. The article adds that, in addition to the operational improvements just described, there were savings of \$125,000,000 in recovered downtime and \$15,000,000 in reduced maintenance.

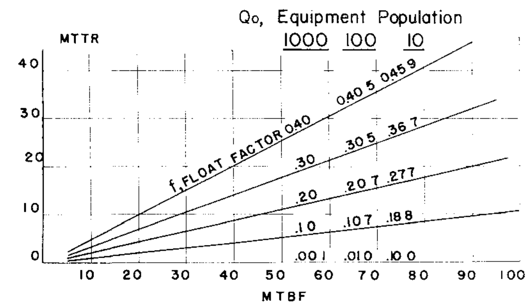

Fig. 3 Maintenance float factors.

To sum up, changes in reliability and maintainability can be measured by their effects on the maintenance float; these effects are quite pronounced, are fairly linear in the ranges normally used, and can be expressed both as technical float factors and in money terms.

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Stability Derivatives by Rheoelectric Analog

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Introduction

THE use of the electrical analog to solve aerodynamic problems is well known. The electrical analog method for determining apparent masses was suggested in the Journal of the Royal Aeronautical Society in April 1965. However, with the method used at Norair, integration in the complex plane is not required. The required answer can be accomplished basically with but one simple measurement of resistance. The method can also be extended to use an electrolytic tank to obtain apparent masses for arbitrary three-dimensional shapes.

Northrop Norair has been working for a number of months on a NASA contract to study the aerodynamics of lifting reentry bodies. This study includes investigation of both static and dynamic coefficients over a wide range of Mach numbers. Its main purpose is to develop estimating methods applicable to lifting bodies in general; results are being applied to the NASA M-2 and HL-10 vehicles.

Slender body theory seemed promising for application to this program. The basic idea of slender body theory is that each body cross section can be studied independently of other cross sections, and the aerodynamic force contribution of each can be summed over the body length to obtain aerodynamic stability derivatives (see Fig. 1). The important parameter

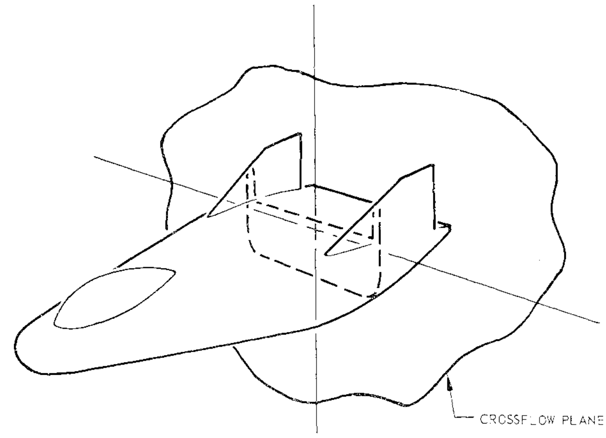

Fig. 1 Slender body theory.

of each cross section which allows computation of these derivatives is the apparent mass.

In the case of a single body moving through an otherwise unbounded and undisturbed infinite fluid, it can be shown that the entire effect of the fluid may be represented by the addition of apparent masses to the inertia of the solid. It is desirable, therefore, to determine simplified methods for evaluating apparent masses for fluid flow.

Application of Electrical Analog

In two-dimensional flow, a relationship between apparent mass and the complex function describing the flow can be found. The relationship between the apparent mass and the flow function shows that the determination of the residue of the flow function will allow calculation of apparent mass. However, determination of this residue is not mathematically simple for arbitrary shapes. Therefore, some simple measurement, such as using an electrical analog technique, may be useful. Following this clue led to the method described here, which utilizes measurements of the apparent resistance presented by an arbitrary shape cut out of a sheet of electrically conducting paper.

To illustrate this concept, consider the following. For two-dimensional flow, the relationship between apparent mass and the flow function for an arbitrary shape is

$$\begin{aligned} A_{12} - i(A_{11} + \rho s) &= \rho \oint w_1 dz \\ A_{22} + \rho s - iA_{12} &= \rho \oint w_2 dz \end{aligned} \qquad (1)$$

(see Ref. 1), where w_1 is the complex potential for a unit flow in the x direction, and w_2 is for unit flow along y. Also, A_{ij} is the apparent mass in the i direction due to flow in the j direction, and $\oint wdz$ is $2\pi i$ times the residue of the flow function.

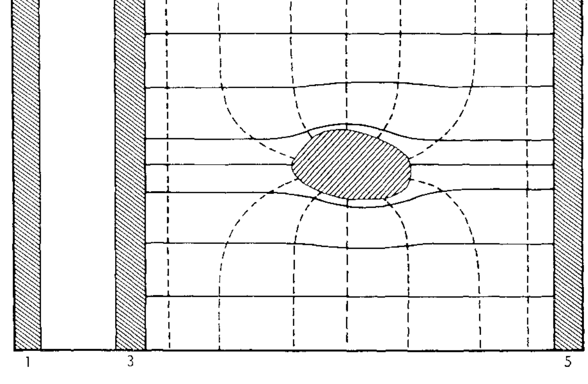

Fig. 2 Residue evaluation.

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