Table 3 Possible rotational lines or bands of hydroxyl radical for monitoring equivalence ratio of hydrogen-air flames

Wavelength, Å	Transition	Reference
	Emission	
5,126 BH[a]	$B^2\Sigma^+ \rightarrow A^2\Sigma^+$ (0, 7)	18
5,534 BH	$B^2\Sigma^+ \rightarrow A^2\Sigma^+$ (1, 9)	18
3,064 BH	$^2\Sigma \rightarrow {}^2\pi$ (0, 0)	19
3,064 BH	$^2\Sigma \rightarrow {}^2\pi$ (0, 0)	12
28,027	$^2\Sigma \rightarrow {}^2\pi$ (0, 1)	15
14,345	$^2\Sigma \rightarrow {}^2\pi$ (0, 2)	15
	Absorption	
...	$^2\pi \rightarrow {}^2\Sigma^+$	17
3,064	$^2\pi \rightarrow {}^2\Sigma$ (0, 0)	16

[a] BH = band head.

The development of a combustion monitor for hydrogen-air flames would be based on suitable experiments with the combustion chamber operating over widely varying conditions. The experiments yield the values of spectral intensity ratio (SIR) which indicate favorable combustion and those which indicate unfavorable or dangerous conditions. With the correlation of SIR and desirable operating conditions, a control device can be developed. Intensity of radiation depends on the effect of all emitters spatially distributed over the optical path. A boundary layer with its gradients in temperature and concentrations may cause difficulties with spectroscopic methods. The ratio of boundary-layer thickness to stream width is an important parameter for evaluating boundary-layer effects. Inlets are designed to make this quantity small; otherwise, diffuser losses become intolerable.

It is conceivable that a SIR monitor would be a valuable aid to maintaining fuel economy on long range flights of jet transports or bombers. Use of SIR as a combustion monitor is not limited to supersonic combustion but has superior features for subsonic-combustion ramjets, turbojets, and turboprops. SIR provides direct monitoring of the flame and fast time response, so that an impending flame-out can be detected.

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What Is a Man-Rated Booster?

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THE primary purpose of this note is to change the approach to the design of launch vehicles destined to carry man into space. The proposal consists of adding to today's state of the art the interconnection of systems coupled with much greater utilization of the astronaut's judgment and more extensive systems flight test in order to get the most out of the man-machine combination. A brief history of actions taken to produce today's man-rated booster is offered to show that a uniform approach does not exist. A basic definition of man-rating consistent with the previous intent is offered:

A booster is considered as man-rated when its design permits an astronaut alternate equipment choices and alternate capabilities through participation in the propulsion and guidance control functions and, in addition, in the course of the booster flight test development, it is as deliberately as possible exposed to the critical design conditions to assure its capability to perform adequately in the real mission environment.

The actions involved in "man-rating" Atlas Mercury, Titan Gemini, Saturn, and Titan III can be classified into six general headings: 1) motivation of engineers and technicians to be more careful in their work, 2) hardware changes for increased booster and spacecraft reliability, 3) hardware changes to enhance mission success, 4) hardware changes for astronaut personal safety, 5) special handling and selection of parts, and 6) astronaut training. The specific actions applied to each of the boosters is markedly different. No fundamental criteria form the basis for all of the actions taken. Each is considered as man-rated in its own inimitable way.

Atlas Mercury (A-M)

The designers of the A-M have worked toward two goals as the basis for man-rating: astronaut safety and success of the

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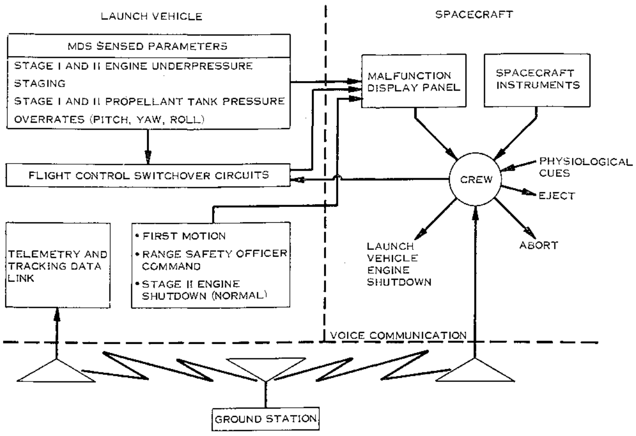

Fig. 1 The Gemini malfunction detection system.

scientific mission. The major action with respect to the A-M booster to help assure astronaut safety was the design of an Abort Sensing Implementation System (ASIS), a combination of redundant sensors and circuitry that provides an automatic abort command prior to any catastrophic failure. The parameters monitored are attitude rates, tank pressures, fuel manifold pressures, hydraulic pressure, and electrical power. The design incorporates redundancy in sensors and circuitry. ASIS is supported by an abort system designed to lift the spacecraft away from the booster when automatically triggered by ASIS.

The second goal, "success of the scientific mission," was the basis for 1) an educational program to motivate people for better quality (motivation and reliability); 2) redesigns around "faulty parts" (reliability); 3) special selection, storage, and handling of parts to assure higher quality (reliability); and 4) "roll-out inspection" that reviewed the hardware and the test program for each booster to assure the elimination of any shortages, 100% functional integrity, and the explanation of all anomalies (reliability).

Gemini Launch Vehicle (GLV)

The designers of the GLV used the following as the basis for man-rating: "Man-rating of the GLV is defined as the philosophy and plan for marshalling the disciplines necessary to achieve a satisfactory probability of crew (astronaut) survival." The design incorporates component and/or system redundancy in the flight control system and the electrical system. In addition, launch vehicle failure modes have been assessed and serve as the basis for the design of a Malfunction Detection System (MDS) that employs automatic as well as crew-activated modes. The system is relatively simple. Sensors are associated with Stage I and II engine underpressure, staging, Stage I and II propellant tank pressures, and pitch, yaw, and roll overrates (Figs. 1 and 2). Of 97 qualified airborne components, 54 are designated as "critical," meaning that their failure results in crew abort, significant decrease in probability of mission success, a hold or kill in countdown which leads to missing launch window requirements, or a unique design not heretofore used on a manned vehicle. The components so designated have extra and special requirements for identification, tolerances, repair approvals, configuration and process control, test requirements, storage, and handling. A more detailed presentation of the Gemini man-rating actions is available in Ref. 1.

Titan III and the Product Integrity Engineer

For Titan III, a product integrity program has been applied to all operations of the vehicle design, manufacture, and test plus the installation of an MDS in the rocket. The following

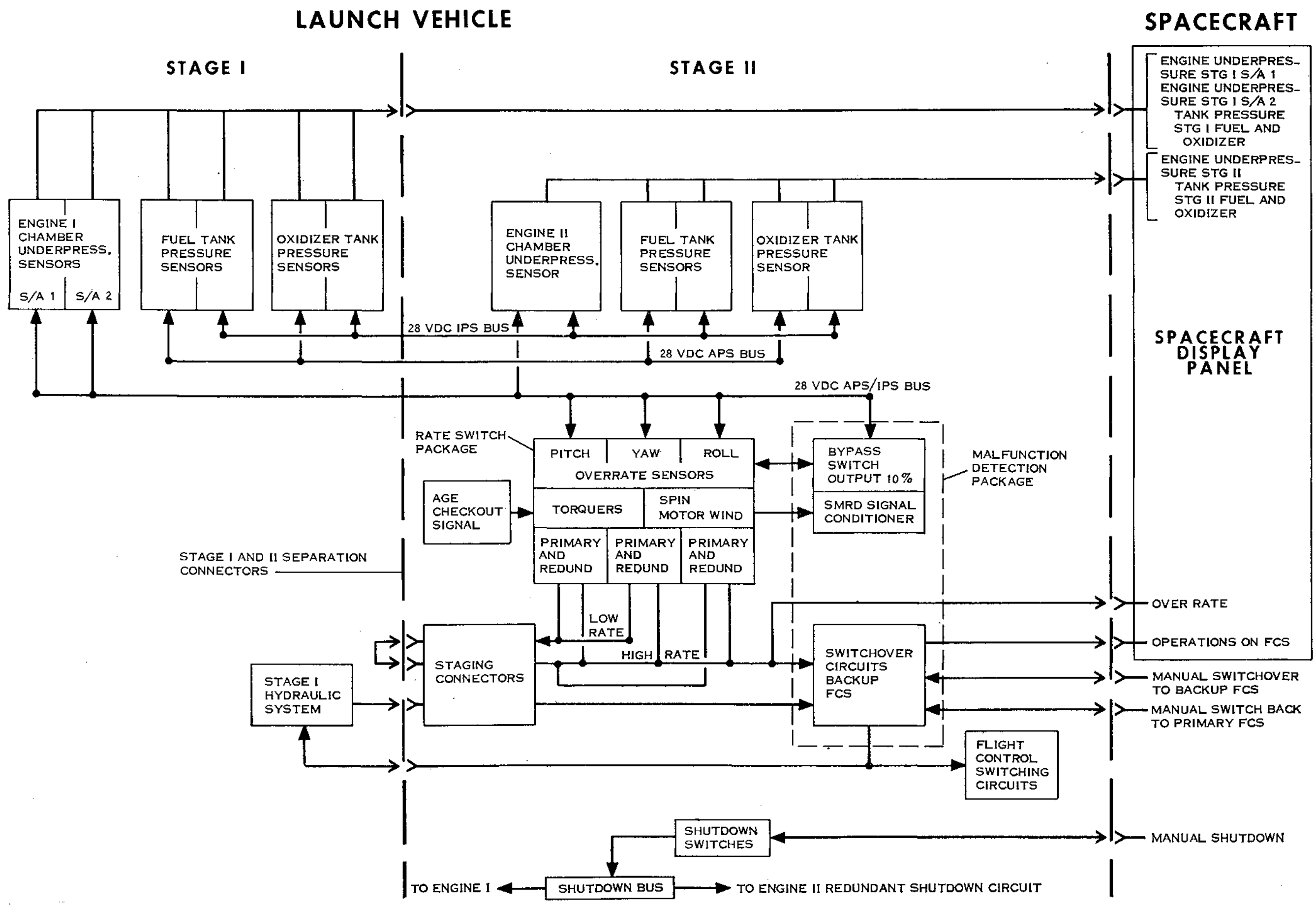

Fig. 2 Typical MDS sensors and display.

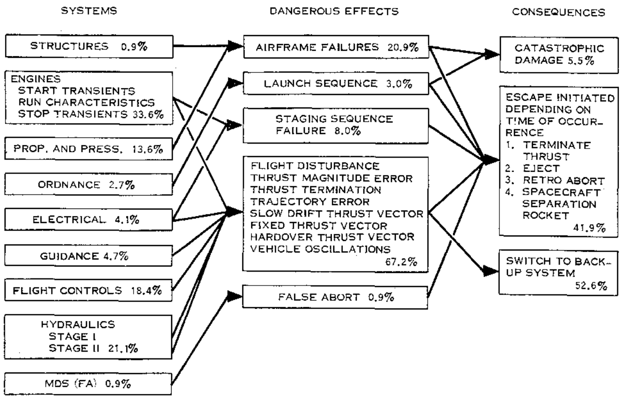

Fig. 3 Malfunction events.

general questions were posed:

1) Does the design satisfy the performance requirements?

2) Is the engineering information complete and accurate?

3) How does manufacturing control its operations to deliver "flight ready" hardware? What controls are necessary to obtain "flight ready" items a) from suppliers and b) as Government Furnished Equipment (GFE)?

4) What controls are necessary to deliver "flight ready" associate equipment to a) manufacturing, b) vertical test, or c) Atlantic Missile Range (AMR)?

5) How can procedures be prepared to reduce human-induced failures?

6) Does the test program evaluate all aspects of the performance capability of the system?

7) Are the flight preparations and prelaunch activities adequate?

8) What change control practices are necessary to achieve performance requirements?

9) How is system effectiveness achieved? Maintainability? Safety?

10) How does quality assurance program support reliability?

Each of those general questions was subdivided, and each resulting item was assigned to an individual. For example, the first portion of 3 was expanded into 21 subheadings; such as, staging inspections of hardware, data package or history of item, control of outside vendor processes, specifications, and unchanging conformance thereto, periodic production planning reviews, tool configuration control, special tags and/or decals for all parts in a "special handling" category, production environmental tests, hardware integrity tests, incremental acceptance reviews, production monitoring tests, and storage practices for control of spares.

A most significant action was the assignment of Product Integrity Engineers (PIE) to follow specific pieces of hardware through the whole loop. Each PIE was told to make judgments on the basis of whether or not he would be willing to literally ride on the front end of the rocket containing his piece of hardware. The PIE affixes his signature to any and all engineering progress tickets that release engineering against his hardware and reviews all deviations occurring during procurement, manufacturing, test, or usage. It is expected that any significant deviation in the course of the operation would be brought to his attention as an in-line action with approval at the time of occurrence. The intent is to instill strong conscientious thought that life depends on the satisfactory operation of *each and every piece of hardware.* In this regard, the Technical Operations Executive Director and Directors have endorsed and pledged their cooperation, and the PIE functions were more formally identified in a policy document as follows:

1) to be responsible and be personally convinced that the design and the as-built hardware are capable of fulfilling the Titan III mission objectives; 2) to specifically participate in incremental reviews, final acceptance, system compatibility firing, and launch for the following: a) design description, functional operation, and specification requirements; b) design analysis to prove that test anomalies and hardware discrepancies do not degrade performance; c) approval of development test results and design assurance test; d) incremental reviews for subassembly, final assembly, vertical test facility, and hardware acceptance; and e) final acceptance for PIE assigned items; and 3) to be prepared to explain with personal conviction and factual data to either company management or the customer that all discrepancies and anomalies in the hardware have been reviewed and brought to a condition where they are acceptable.

The full document defining the functions of our PIE's is seven pages long. The approach has been most effective. Problems are identified sooner and attacked with a much stronger sense of personal responsibility.

The MDS designed into the Titan III is based on a malfunction events assessment similar to that shown in Fig. 3. The actual hardware is similar to that of the GLV shown in Figs. 1 and 2.

Design and Testing for Man-Rating

The first conceptual designs for a manned system should be assessed for *all* possible malfunctions and for ways that man, being a part of the system, might be able to either circumvent or minimize the impact of a given malfunction. Each possible failure (Fig. 3) is studied; we consider how the astronaut could either switch to alternate sources of energy to perform the function affected, or, with additional equipment, switch to an alternate or redundant set of gears and continue his mission, or move to the next sequence of flight operations and hurdle over the malfunction confronting him. The emphasis should be on those areas where experience indicates the major failures have occurred, i.e., engine system, pressurization system, guidance, control, and staging (Fig. 3). There is a need to emphasize the approach of switching to alternate sources of energy to perform a function. All of the boosters cited, for example, contain separate pressurization systems for propulsion in each of their stages. A failure in an early stage could be provided for by interconnection with and utilization of the pressurization equipment in higher numbered stages. This is only one of more than a score of examples that could be offered in the propellant and pressurization, flight stabilization, guidance, electrical, and tracking and flight safety systems. This approach has tremendous untapped potential for a higher level of mission success for the man-machine combination.

Another important consideration is uniformity in the margins of safety employed. Today's booster state of the art does not present the case for a fairly uniform collection of margins of safety on equipment. It is proposed to examine each function that the machine must perform and measure the degree of risk and the pilot's speed of reaction to determine the appropriate margin of safety for that particular piece of equipment in order to make the most of the man-machine relationship. No single failure should be the cause of a catastrophic malfunction. An MDS is an inherent part of any man-rated booster; in some modes of flight for today's boosters, the escape mode may have to be automatic when failure is catastrophic in too short a time for pilot reference. It is pertinent to ask whether the aerostructures design could be altered to minimize such a case.

An important part of man-rating a booster is a flight test program that deliberately encompasses critical design conditions. Consideration must be given to flight in the design ground winds and design high altitude winds, to deliberately induced rapid changes in attitude, to excursions of the thrust chamber, and to possible malfunctions in the electrical and electronic systems. The intent is to be able to state to the astronaut that the machine has been exposed to the design conditions for which it was originally intended and that, in effect, he can take confidence from its performance throughout the design regime. It is expected that extra instrumentation would be provided in the course of the flight test program and that some manned flights would be included to get the most out of the man-machine during this portion of its development, so that subsequent operational flights could be as reasonably foolproof as possible.

What Man-Rating Is

In summary then, man-rating is emphasized as those elements of today's state of the art such as: 1) part or component traceability to insure design integrity, reliability, and configuration control; 2) extra care in the design and manufacture of equipment; and 3) an explanation of all the anomalies in the handling and testing of the equipment in component, subsystem, or total system form; and, in addition, a design for which possible malfunctions have been assessed and in which the pilot is given alternate choices in both mission and equipment so that his judgments are brought to assist in the performance of the mission. He is given a guidance and control capability (possibly coupled with a thrust control capability), a malfunction detection system, margins of safety that are consistent with the degree of risk and his speed of reaction, and a design where no single cause is likely to result in a catastrophic system failure. He has a vehicle that has been flight tested in the design conditions.

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Preliminary Nozzle Weight Determination

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A NEED has long existed for a simple, rapid, and reasonably accurate method of determining specific nozzle weights for the preliminary design of solid-propellant rocket motors. "First pass" nozzle weight values are essential to tradeoffs between propulsion system weight and delivered performance. Accordingly, a simplified method of nozzle weight determination from parametric graphs for one typical propellant is presented as a design tool. Chamber pressure (P_c, psi), weight flow rate ($\dot{w}$, lb/sec) or throat area (A_t, in.^{2}), and motor action time (τ, sec) are the primary input parameters, and auxiliary charts permit determination of the effect of expansion area ratio (ϵ). Charts have been developed for both 15° half-angle conical nozzles and 80% bell contour nozzles for chamber pressures of 500, 1000, 1500, and 2000 psi. Only the 1000-psi figures are presented in this note. Working charts for all four pressures are given in Ref. 1, which the author will supply to the reader on request.

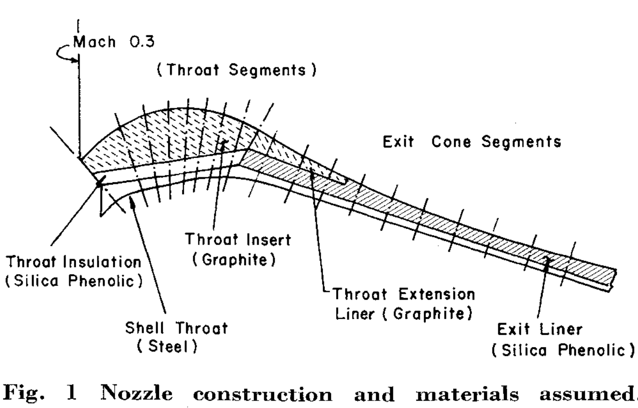

Fig. 1 Nozzle construction and materials assumed.

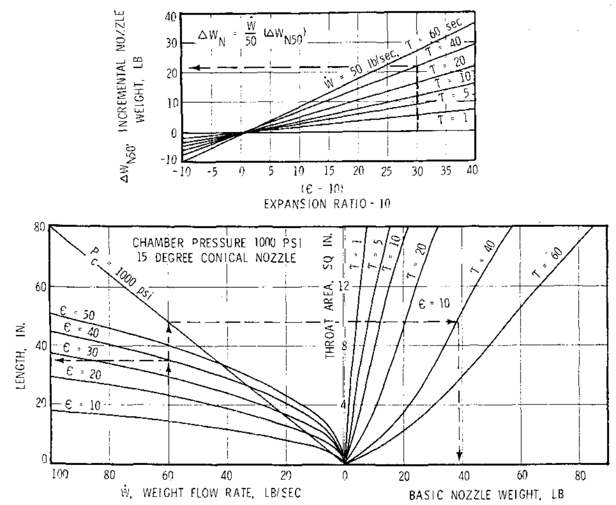

Fig. 2 Chart for determining weight of 15° half-angle conical nozzle.

The analysis and computations made for the parametric curves resulted from a nozzle design and weight optimization study using a computer program. Nozzle configurations may have either bell or conical contours designed to appropriate half-angle requirements. The nozzle design is based on a heat- and mass-transfer analysis, and material weights are determined by representative nozzle material properties that provide adequate structural integrity for given flow conditions. The accuracy of this program has been repeatedly demonstrated by comparing the predicted nozzle weight with detailed board design layouts.

Nozzle Design and Computer Program

Figure 1 illustrates the nozzle construction used for both conical and contoured nozzle designs considered. (Nozzle weights given by the curves do not include the nozzle attachment flange.) Properties of the silica phenolic and graphite are given in Table 1. Weight flow rates were determined from inputs of throat area, chamber pressure, and propellant characteristics. The propellant properties and conditions shown in Table 2 were utilized. (Throat erosion was considered negligible.) The computer program divided the

Table 1 Properties of silica phenolic and graphite

Silica phenolic	
Ablation temperature, °F	3500
Thermal conductivity, Btu/hr-ft-°F	0.25
Heat of ablation, Btu/lb	4000
Density, lb/in.^{3}	0.064
Graphite	
Density of graphite, lb/in.^{3}	0.069
Thermal conductivity, Btu/hr-ft-°F	72

Table 2 Propellant properties and conditions

Flame temperature, °R	6460
Ratio of specific heats γ	1.20
Characteristic exhaust velocity c^*, fps	5100
Reference specific impulse $I_{s\ ref}$ at all P_c, lb-sec/lb	250
Reference thrust coefficient $C_{f\ ref}$	1.595

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