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AGARD MEETING ON "AIRCRAFT ENGINE NOISE AND SONIC BOOM," FRENCH-GERMAN RESEARCH INSTITUTE, ST. LOUIS, FRANCE

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UNITED STATES OF AMERICA

AGARD MEETING ON "AIRCRAFT ENGINE NOISE AND SONIC BOOM"

FRENCH-GERMAN RESEARCH INSTITUTE, ST. LOUIS, FRANCE, 27-30 May 1969

Introduction

The NATO Advisory Group on Aerospace Research and Development (AGARD) held a meeting on "Aircraft Engine Noise and Sonic Boom" at the French-German Research Institute, St. Louis, France, 27-30 May 1969. The meeting was jointly sponsored by AGARD's Fluid Dynamics Panel, and Propulsion and Energetics Panel.

St. Louis is a French town of about 15,000 inhabitants, close to both the German and Swiss frontiers. The nearest cities are Basel, in Switzerland, and Mulhouse, in France which share a common international airport, located in French territory in the commune of Saint-Louis.

North of St. Louis and Basel on the left bank of the Rhine is the French province of Alsace, with the cities of Colmar and Strasbourg, and on the right bank is the German province of Bade Wurtemberg, with the cities of Freiburg and Karlsruhe. These provinces are separated by the Rhine and bounded to the west and east respectively by mountainous areas - the Vosges in France, and the Black Forest in Germany. Both provinces are lands of ancient culture, whose towns are still full of magnificent old mansions and abbeys, churches and cathedrals built in gothic style. They are lands of gastronomy, well known for trout and sauerkraut and also, especially, for excellent white wines.

The meeting was held at the French-German Research Institute, known as "Institut de Saint-Louis", or simply "I.S.L."

This Institute is active in research on hypersonic flow, using light-gas guns and shock tubes, and on shock waves, particularly sonic booms. It also deals with an extended field of research related to physics, ballistics and measuring devices for hypervelocity phenomena.

The meeting consisted of seven sessions. These sessions were:

I. Survey and Review Papers

II. Engine Noise Generation

III. Sonic Boom: Generation and Propagation

IV. Engine Noise Reduction

V. Engine Noise

VI. Sonic Boom

VII. Real Aircraft Noise

During the introduction to the meeting, some time was spent explaining why AGARD, which is oriented toward military technology, was interested in the noise problem. It was pointed out that the military must often pay the bill for damage claimed to be caused by sonic booms, and that the military must consider the social problems its technology might create.

Statistics on attendance and presentations are as follows:

Country	Attendees	Papers Presented
Belgium	7	0
Canada	6	1
Denmark	3	0
France	43	8
Germany	46	2
Italy	4	1
Netherlands	8	0
Norway	2	0
Switzerland	4	0
Turkey	2	0
U.K.	23	6
U.S.	45	14
Total Europe	142	17
Total U.S. + Canada	51	15

The remainder of this report is devoted to the papers which were presented. The summaries contained herein are the abstracts or summaries given by the authors. The comments following the abstracts are based upon statements made in the pre-prints and presentations, the discussions which took place after each presentation, and the personal observations of this writer.

PHYSICS OF NOISE by G.M. Lilley (University of Southampton, England)

Summary - This paper not only sets out the unified theory of aerodynamic noise involving random disturbances in the flow, but also shows how the theory can include the analysis of the pressure fields from bodies traveling through otherwise undisturbed air at sub and supersonic speeds, and therefore includes the theoretical background for the treatment of the sonic boom problem for generalized aircraft motions. A number of examples of various applications of the theory are given with comparisons with experimental results.

Comments - Unfortunately the first presentation was very difficult to follow. The author kept referring to pages in his paper, but his pre-print was one of a very few which had not been handed out prior to presentation. The author ended his presentation with a plea for experimentalists to change variables in any noise experiment one at a time, since changes in many variables from test to test make it almost impossible to isolate the effect of the variables. He felt that in particular Reynolds number effects should be isolated from those of Mach number.

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A BRIEF LEGAL HISTORY OF THE SONIC BOOM IN AMERICA by J.P. and E.R.G. Taylor (National Academy of Sciences, Washington, D.C.)

Summary - In this paper sonic booms and their effects on man and his structures are examined through material available from administrative claims and court cases. Several recent Congressional actions and early response thereto by the Department of Transportation, and Federal Aviation Administration insofar as the sonic boom is concerned, are briefly described.

Comments - This analysis of the legal aspects of noise problems appeared to generate more interest than might normally be expected at a meeting of technical specialists. As the session chairman, A. Auriol of France, pointed out, the noise problem is a mixture of mathematics, engineering, science, and human problems. Apparently Auriol himself had recommended that a legal analysis be included in the agenda. No doubt was left by the authors about the keen interest of the Congress, FAA, Department of Transportation, and Air Force in the legal problems created by noise.

AIRPORT DESIGN AND OPERATION FOR MINIMUM NOISE EXPOSURE by Isaac H. Hoover (Office of Noise Abatement) and Donald G. Cochran (Airports Service, Federal Aviation Administration, Washington, D.C.)

Summary - This paper examines the expected noise exposures to be generated by commercial aircraft operating in the next decade and reviews significant considerations in the location of new airports, the land requirements of existing and new airports as a function of the type service, and airport design in terms of runways and necessary support facilities to minimize noise exposure. The potential of existing and developing operational practices and restrictions to minimize noise are assessed. Finally, the forecasting of aircraft noise exposure near airports and its relationship to the development of compatible land use programs and public relations/education programs are discussed.

Comments - This paper was well presented by Cochran, and generated considerable discussion. Cochran pointed out that the US is transitioning from the Composite Noise Rating system for describing noise exposure, to the Noise Exposure Forecast. The latter system incorporates three features: 1) the EPNdB (Effective Perceived Noise Level) unit for describing flight noise exposure is replacing the PNdB unit; 2) the total exposure from all operations and the penalty for night operations is being calculated in smaller increments; and 3) the numerical scale is being changed to avoid confusion between single flight noise level rating and the cumulative noise exposure ratings. In response to a question, Cochran noted that the FAA has no plans for directly controlling noise per se; rather control is to be exerted through FAA certification and operational procedures.

PROBABILITY OF AIRCRAFT NOISE AND SONIC BOOM INDUCED BUILDING DAMAGES by Dr-Ing Gunter Weber (Technical University, Hanover, Germany)

Summary - Buildings are calculated for certain static deadloads and payloads, prescribed by building standards. Aircraft noise and sonic booms are transient supplement loads, neglected in calculation. Scope of this paper is the evaluation of the ratio of calculated static main stresses to dynamic supplement stresses induced by aircraft noise and sonic booms.

Aircraft noise with sound pressure levels from 81 dB to 92 dB produced stresses up to $\sigma = 0.8$ kp/cm^2 in glass panes of a multistory building.

For an old church and a residential structure excitations producing limit stresses were calculated and compared with overpressures measured in booms. Boom generated supplement stresses in primary parts of buildings will reach less than 1% of allowable stresses, in roofs less than 10%, in glass panes up to 50%, unfavorable circumstances presupposed.

Damage therefore will follow a certain order:

Primary structures like walls, staircases, etc., only could be influenced if before parts of the roof would be damaged. Tiles on the roof would crack before rafters would reach their stress limit. Glass panes would break before damage on roofs would happen. Unsound plaster with adhesive strength approaching zero would fall off at first. Damage on primary structures of buildings are till now known and are not to be expected.

Comments - Weber contributed an interesting view of the sonic boom problem: that of the civil engineer. Theoretical analysis was coupled with experimental data obtained in a test program of 25 controlled sonic booms aimed at typically European structures. This work could be a useful supplement to analyses in the US.

HUMAN RESPONSE TO SONIC BOOMS by Dr. H.E. von Gierke and Dr. C.W. Nixon (Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio)

Summary - This paper reviews the results of the various observations, overflight programs, experimental field and laboratory tests, which form the basis for present day estimates regarding the acceptability of sonic booms by man. The loudness and annoyance of individual booms and their dependence on the boom overpressure and pressure time function as well as the complex reaction of individuals, groups and cities exposed to sonic booms of varied magnitude and frequency are discussed. The few experiments available proving that even sonic booms of the maximum intensity presently feasible cannot produce any direct medical injury are described. Based on the integrated body of results of recent physiological, psychoacoustic, behavioral and sociological studies in various countries, estimates of the effects and acceptability of regular, frequent supersonic commercial overland flight schedules are presented and discussed in terms of aircraft noise pollution in general and of potential

certification of aircraft with respect to noise and sonic boom. The desirability and limitations of additional research studies to support such administrative decisions is explained.

Comments - Nixon presented the paper. He emphasized that it is extremely difficult to predict the public acceptability of sonic booms. His test data showed that even though the stimulus (boom level) may remain constant over a period of time, complaints and damage claims vary widely. For example, public attention such as newspaper articles can cause an increase in complaints and claims. In response to a question, Nixon said that a flattening of the N-shaped wave can increase acceptability, provided both the positive and negative peaks are flattened.

TURBOFAN ENGINE NOISE - MECHANISMS AND CONTROL by Dr. C.G. Gordon (Bolt Beranek and Newman Inc., Van Nuys, California)

Summary - Data are presented from engine and laboratory studies that illustrate the importance and suggest the parametric dependence of some of the noise sources within a Turbofan engine. These sources seem to play a particularly significant role in the turbine and fan exhaust ducts of an engine -- a role which may be augmented, rather than diminished by current techniques of engine quieting.

There is much to be learned about these sources before their significance in current and projected engine designs can be properly understood. Part of this understanding may derive from careful and systematic studies of current vehicles. Some ideas are suggested for such a study.

Comments - Gordon's paper suggested that classical jet noise can become subservient to internal engine sources when tail-pipe velocities are reduced. He also showed that the role played by pressure losses in a system is important Many current noise suppression devices (duct liners, etc.) impose significant pressure losses; thus their use may not be entirely beneficial. Also he said that the role played by quadrupole sources in the wakes of fixed and rotating blading has not been adequately examined. Finally, the presence of significant sources of broadband noise radiation sources within an engine may cause jet prediction schemes to underestimate the extent of exhaust noise.

NOISE ASSOCIATED WITH SHOCK WAVES IN SUPERSONIC JETS by D.L. Martlew (National Gas Turbine Establishment, Pyestock, Farnborough, Hants, England)

Summary - Noise fields are compared for jets with and without shock cells and similarities are pointed out between the phenomenon of jet screech due to shock cell oscillation and the forward throw of broadband noise. Limited tests with a plug nozzle show that this type produces less forward noise, probably owing to differences in the shock system which is of small extent and irregular in comparison with that of a convergent nozzle.

It is concluded that the elimination of the shock cell pattern could reduce jet noise forward of the nozzle by 10 dB.

Comments - Martlew did an excellent job in showing the importance of keeping the shock out of the system. He displayed sufficient experimental data to lend emphasis to his argument. This research could probably be put to good use in the NASA Quiet Engine program. In his experiments, a conical-convergent nozzle was used to obtain data on jets with a shock cell structure. These data were compared with results of subsequent tests with a plug nozzle, which largely prevents the formation of regular shock cells. The plug nozzle was quieter by about 2-3 dB in the peak direction. In the limit, convergent-divergent nozzles free of shocks at supercritical design pressure ratios might be expected to show an absence of the high-frequency broadband noise.

JET NOISE FROM MOVING AIRCRAFT by Dr. J.E. Ffowcs Williams (Department of Mathematics, Imperial College, London, S.W.7, England)

Summary - The paper sets out an exact equation for the sound field radiated by an aircraft in steady flight. The jet exit flow is assumed perfectly steady. The exact equation is too general to be of practical value, and the paper then sets out precisely the assumptions that are usually made to reduce the exact equation to a manageable engineering formula. The consequence of each particular assumption is emphasized and the theory is presented in such a way as to accept easily new models of the jet flow. The main new contribution in the paper is the development of a scaling formula for the noise of very high-speed jets in flight.

Comments - Ffowcs Williams presented his paper with the authority which is associated with complete confidence and competence. The basic paper contained nothing too new; it concentrated on a discussion of the assumptions underlying the author's previously published theories. However, he added a discussion of some new water-table analogies; these will be described in future papers in conjunction with Rolls Royce.

DETERMINATION OF JET AIRCRAFT NOISE FIELD by M. Kobrynski (ONERA Châtillon-sous-Bagneux, France)

Summary - The relation between the total noise pressure field generated by a stationary axisymmetric jet and the noise field produced by the same jet when moving, as observed from a fixed point on the ground, is studied by introducing in the generalized equation of the local overall sound pressure level a new convection index derived from the RIBNER expression:

$$\left[(1 - M_c \cos \Theta)^2 + {}^{2}_{M_c}{}^{2}) - 5/2 \right] (1 + \cos^4 \Theta)$$

The new equation confirms the previous results for the direction of the maximum sound radiation ΘM and improves noise prediction for the other directions.

The influence of the speed of flight on sound emission within a broad range of angles (20° -160° in relation to the jet axis) is stressed; from there is derived the relation between the convection effect of vortices in stationary and moving jets and the variation of acoustic power produced by the attraction of the jet into the atmosphere.

The results of the analytical study, confirmed by considerable experimental checking, in particular for the angles different from ΘM, have shown that the relative speed is not the significant parameter to be taken into account to determine the overall local noise pressure levels.

Comments - A comment made from the floor implied that the theoretical foundations used for the model presented were not as rigorous as might be required. It was therefore implied that the model may be limited in its present form.

ANALYSIS OF NOISE INTERFERENCES DUE TO REFLECTION. APPLICATION TO JET NOISE PRESSURE SPECTRA by P. Thomas (Snecma, Centre d'Essais de Villaroche, Moissy-Cramayel, France)

Summary - The results presented in this paper deal mainly with the influence of reflection on jet noise pressure spectra.

The expressions of the reflection indices resulting from the presence of a reflective or partially absorptive surface are presented.

However, the pin-point source assumption which may be considered, under certain conditions, in the case of remote noise field measurements, is no longer applicable when the jet is close to the ground. For such particular cases, a reflection theory based on a distribution of independent elementary sources is developed. Experimental tests on model jets, mainly with perfect reflectors have been carried out in a silent chamber and have established the validity of the theoretical relations developed.

Comments - No questions were posed by the audience, which surprised A. Ferri of the US, the session chairman. Ferri felt this was an area of great importance to engine designers. Therefore Ferri asked US participants what is done in the States in terms of corrections. Representatives from two different US engine manufacturers said that they have conducted similar experiments. One stated that corrections are not so important in fan systems, because of dampening.

THE SONIC BOOM OF BODIES OF REVOLUTION by K. Oswatitsch (Inst. für Theoretische Gasdynamik, 51 Aachen, Germany)

Summary - This paper briefly outlines recent work on the sonic boom problem done at the DVL-Institut für Theoretische Gasdynamik. The problems treated with the aid of an analytic method of characteristics are:

1. Sonic boom generated by inclined and non-inclined bodies of revolution moving at a constant supersonic speed.

2. Sonic boom generated by a non-inclined body of revolution moving at an increasing or decreasing transonic speed.

3. Influence of the isothermal stratification of the atmosphere on the sonic boom.

It turns out that the widely used asymptotic formulas are unsatisfactory at altitudes of practical importance.

Comments - None

FOCUSING IN NON LINEAR SHORT WAVES; Application to Ballistic Focusing Noise by J.P. Guiraud, (ONERA, Châtillon/Bagneux, France)

Summary - The theory presented here, which uses only the intrinsic properties common to all the physics phenomena that one wishes to describe, allows the nature of the approximations carried out to be brought out very clearly and the progress of the theory to be understood. Calculation complications, which are essentially of an algebraic nature, take place only at the stage of applications to specific physical phenomena, in particular in the case of the supersonic focusing boom.

Comments - Guiraud emphasized that the phenomenon of focusing is always, essentially, a linear phenomenon. However, in the ensuing discussions someone indicated that if one calculates the maximum pressure using linear theory, the result will be infinity. Therefore, to get a finite maximum pressure, one must use a non-linear approach. The author offered no rebuttal to this statement.

SONIC BOOM REFRACTION AND REFLECTION by Ch. Thery (France) (Institut Franco-Allemand de Recherches de St-Louis)

Summary - For a very long time, there was no reliable method available for quantitatively analyzing focusing phenomena. As a preliminary approach to this problem, the refraction of low intensity stationary shock waves in non-homogeneous atmospheres has been studied. This study has been restricted to the simple cases of the two dimension propagation of an N-shaped wave in an axisymmetrical atmosphere and of a step wave in a stratified atmosphere. Calculation methods are based on shock properties. Numerical results obtained

correlate well with flight test data. The refraction of a step wave is described by a differential equation for which approximate solutions can be found; these solutions offer analogies with some results obtained by J.P. Guiraud; this might permit an extension of the results obtained to non-stationary flights.

When the wave almost brushes past the ground, the reflection effect may be increased. In practice, this particular phenomenon occurs almost simultaneously with focusing in accelerated level flight.

Comments - Thery said his theoretical results are consistent with the experimental results obtained in the French "Jericho" project on focusing. (See following paper by Wanner.)

MIRAGE IV - FLIGHT TESTS by I.C. Wanner, (Serv. de l'Aéronautique/EG, 4, Av. de la Port d'Issy, Paris 15ème, France)

Summary - A complete series of studies on focusing has been undertaken. The initiation and location of focusing can be predicted by means of a simple method of propagation calculation which also permits the preparation of flight tests. Two series of flight tests were carried out, and forty-three focusings were recorded; as a result, the amplification coefficient can be estimated with reasonable accuracy. The experimental results available on propagation correlate well with calculations.

Comments - Wanner said that one of the reasons the French undertook an experimental program on focusing was that NASA, in a recent report, had said there was inadequate information on the focusing phenomenon. In the program called "Project Jericho," a 3-km axis was selected, with 28 measuring points (about one every 100 m). Both turn and acceleration maneuvers were conducted by a Mirage IV aircraft. 11,000 m and 600 m altitude runs were made. 27 of the measurements that were made were usable. An amplification factor of 5.1 was obtained. The amplification factor is defined as the ratio of Δ P of the focusing run to the Δ P of a reference or straight run. All results are now available in the following report: "Operation Jericho - Virage," Study Report No. 277, May 1969, by J. Vallee, Centre d'Essais en Vol, Istres, France. -- This presentation was one of the highlights of the meeting.

SURVEY OF UNITED STATES SONIC BOOM OVERFLIGHT EXPERIMENTATION by Dr. John O. Powers, J.M. Sands (Office of Noise Abatement, Federal Aviation Administration, Washington, D.C.) and Domenic J. Maglieri (Langley Research Center, National Aeronautics and Space Administration, Hampton, Va.)

Summary - Several survey papers exist, which have reviewed the chronology and the significant findings from overflight experimentation. The present paper utilizes much of the material presented in those references; however, the authors add new and recent material which updates the previous papers. In addition, some recent developments in the claims and legal activity

associated with this experimentation permit us to obtain an up-to-date view of the legal and social costs associated with the test programs. Other recent developments in the field of sonic boom overpressure measuring instrumentation and in the theoretical methods of signature prediction are included. These developments are expected to facilitate future sonic boom overflight studies and will enhance our ability to theoretically interpret the resulting experimental findings.

Comments - The paper was presented by Powers. The paper is comprehensive, and was exceptionally well presented. However, Powers ran into one slight obstacle when he reported that focusing research conducted by NASA in the early 1960's showed that the focusing amplification factor was 2.5-3, not the 5.1 the French obtained (see previous paper by Wanner). A French representative surmised that the microphones in the earlier NASA experiment were not as closely spaced as those in the French program; he implied that perhaps NASA did not precisely see the focusing phenomenon.

GROUND CONFIGURATION EFFECTS ON "SONIC BOOM" by Dino Dini and Renzo Lazzeretti (University of Pisa, Italy)

Summary - The propagation of sonic boom generated in flight operation by a particular aircraft is most significantly affected by ground configuration, due to reflection and refraction in different distribution patterns.

In the present paper, such effects are analyzed for different ground geometries and possible overpressure values.

Here the results of computations are presented in tabular form regarding the cases that may occur in practice.

The results of such analytical procedure is compared with known results obtained in other similar pressure wave propagation.

Comments - Dini's paper was largely a survey of relatively well-known concepts and effects.

THE DEVELOPMENT OF ACOUSTIC ABSORBERS FOR TURBOFAN ENGINES by C.J. Webber (Rolls-Royce Limited, Hucknall Aerodrome, Near Nottingham, England)

Summary - High-bypass-ratio-engine noise is dominated by the fan and turbine sources. Noise from these components may be reduced by the application of absorbent liners to the engine ducts. The design of such liners for optimum acoustic performance requires experimental data on the behavior of absorbent systems in a representative environment. A description is given of a high sound pressure level impedance tube and a large scale absorption flow facility, developed by Rolls-Royce for this purpose. Some results for typical liner designs obtained in these rigs are presented and discussed.

Comments - One important conclusion drawn from the results of tests in the high intensity standing wave tube was that in order to obtain the desired lining impedance (approximately the local characteristic of air) at the sound pressures found inside engine ducts, linings must be fitted which display considerably lower flow resistance measured at low sound levels. Also, the rate of change of resistance with sound pressure level was found to be an important design factor for a lining material, since it influences the extent to which the lining will depart from optimum acoustic performance at off-design speeds. Webber was asked if he was doing his research with human beings or with structures in mind. He replied "Human beings, particularly the FAA."

AIRCRAFT ENGINE NOISE MEASUREMENT TECHNIQUES, FACILITIES, AND TEST RESULTS
by Dr. William R. Morgan (Manager, Quiet Engine Program, Advanced Technology Programs Department, Aircraft Engine Group, General Electric Company, Cincinnati, Ohio 45215) and Dr. Spiridon N. Suciu (Manager, Design Technology Operation, Aircraft Engine Group, General Electric Company, Cincinnati, Ohio 45215)

Summary - This paper describes three basic phases of acoustic testing and analysis work necessary to advance the state of the art of quiet engine designs which, in turn, contribute to the reduction of noise emanating from aircraft. The paper provides a description of types of laboratory test equipment and some important, early results that may be obtained from such equipment; far field (open field) acoustic ground test facilities and test results; and finally, flight test facilities and flight results.

Throughout the paper emphasis is placed on the importance of specifying the noise requirements early (and carrying out early substantiating tests) so that the engine will incorporate the basic features necessary to achieve the specified noise levels at a minimum penalty in performance, weight, cost, and reliability. Also, the need is spelled out for an analytical effort closely integrated with, and parallel to, the experimental work to gain an understanding of the basic mechanisms of noise generation and suppression and to develop reliable prediction methods for system tradeoff studies and future noise level projections.

Comments - Morgan, who presented the paper, described in general terms a technique for predicting perceived noise versus time. Static ground-test noise data are stored in a digital computer. The aircraft is then flown by digital computer and the noise level and specific "tent" noise characteristic are predicted as a function of time. Morgan showed the comparison between actual and predicted results. Many of the attendees apparently thought this was a very enlightened technique. Morgan fended off (somewhat) requests for more detail, saying that people should be cautious, since the technique is in its infancy.

GENERATION AND SUPPRESSION OF COMBINATION TONE NOISE FROM TURBOFAN ENGINES by J.D. Kester (Pratt & Whitney Aircraft, East Hartford, Conn.)

Summary - Advanced acoustical design features have resulted in the elimination of several sources of noise from the JT9D high bypass ratio turbofan engine being developed by Pratt and Whitney Aircraft. With reductions in pure tone noise levels radiated out the inlet duct, combination tone noise has been uncovered as a principal remaining noise source at high powers where the fan blade tips are supersonic. Studies of the generation and propagation of this noise have been conducted on a variety of research rigs as well as on the full scale engine. Detailed mapping of the inlet duct noise field forward of a supersonic tip speed fan has provided a basic understanding of the properties of this noise source. Reductions in the level of noise from this source have been demonstrated by the installation of sound absorbing liners in the inlet ducts of turbofan engines. Results of these studies are reviewed in this paper.

Comments - A series of acoustically treated inlet duct liners was fabricated and tested on a 28-inch diameter rig. Various lengths of liners having different types of treatment were evaluated. Several configurations showed substantial reduction of combination tone noise. In one example used by Kester, the combination tone noise was reduced by about 15 dB with only a short length of treatment. He noted that no reduction in discrete tone noise was achieved. He said that a possible reason for the lack of blade passing frequency tone suppression is that this noise is generated over the whole fan inlet annulus, whereas combination tone noise is concentrated near the outer duct. -- Later in the program, when a paper by another author was canceled, Kester showed in its place a Pratt & Whitney film on noise reduction. This was a thoughtful and perceptive gesture on Kester's part.

ENGINE QUIETING - NACELLE ACOUSTIC TREATMENT by Nelson F. Rekos (Headquarters National Aeronautics and Space Administration, Washington, D.C.)

Summary - This paper describes a major research and development program directed towards reducing the fan noise radiated from the turbofan engines used in current Boeing and McDonnell-Douglas four-engine commercial transports. The reduction in fan noise is expected to be achieved by the modification of the engine nacelles and by the judicious application of acoustically absorptive materials in the fan inlet and discharge ducts. The results of ground tests conducted with full-scale acoustically treated nacelles indicate that fan noise reductions on the order of 12 PNdB to 15 PNdB below the noise levels of the current subsonic turbofan engine installations are feasible.

Comments - Rekos presented an excellent paper, with much recently obtained data. The McDonnell-Douglas nacelle configuration is designed with a co-annular single ring inlet having a total of 64 $ft.^2$ of treated inlet area, and a 48-in. treated fan discharge duct having a total of 70 $ft.^2$ of treated ducted area. The Boeing configuration is designed with a two-ring inlet with 87 $ft.^2$ of area, and a long treated fan discharge duct having a total of 267 $ft.^2$ of treated duct area. Ground test results to date have been encouraging. The contractors are equipping a DC-8 and 707 aircraft with flight rated nacelles to check performance in flight tests.

ENGINE QUIETING - ENGINE DESIGNS by N.F. Rekos (Aeronautical Vehicles Division, Office of Advanced Research and Technology, NASA Headquarters, Washington, D.C.)

Summary - A number of engine design approaches to the solution of the fan noise problem will be discussed along with the basic approach being followed in the development of a Quiet Engine.

Comments - This was another good paper by Rekos, with late data. Based upon extensive studies, it was decided that the baseline JT3D Quiet Engine should have the following characteristics: spacing between rotor and stator blade rows should be equal to at least two rotor blade chords; the number of stator blades should be greater than twice the number of rotor blades; fan inlet guide vanes should be eliminated; bypass ratios should be between 5 and 6; there should be a single stage fan; and design cycle variables should be selected so that the jet noise level is well below the fan noise level to allow margin for acoustic treatment of fan inlet and exhaust ducts.

TURBOJET NOISE EVALUATION METHOD BASED ON THERMOPROPULSIVE VALUES by R. Hoch and J.P. Duponchel (SNECMA, Centre d'Essais de Villaroche, Moissy-Cramayel, France)

Summary - The method proposed for evaluation of turbojet noise is mainly based on detailed calculation methods developed by SNECMA. Unlike usual methods, it permits a very rapid evaluation of noise levels by simple abacus reading.

The thermodynamic parameters generally necessary to such calculations have been replaced by thermopropulsive values which characterize the engine from an overall viewpoint (net thrust, specific consumption, flow rate, by-pass ratio, etc.) and are directly accessible in the descriptive leaflet of a turbo-jet.

The maximum noise (in PNdB) produced by an aircraft can be evaluated either at run up or in flight ($M_o \leqslant 0.5$), for the compressor as well as the exhaust nozzle, whether the engine be a conventional or fan engine.

There is a good correlation between values as measured on board aircraft and values provided by this method.

Comments - The method is partly based upon empirical data obtained from existing engines. A question from the floor raised a doubt that this method could be used on new engines, such as the NASA Quiet Engine, which radically depart from current noise designs. The author was "hopeful" that the technique could be applied in such a case.

ACOUSTIC DATA PROCESSING AND REDUCTION METHODS FOR AIRCRAFT ENGINE STUDIES by J. Hay (ONERA, Châtillon-sous-Bagneux, France)

Summary - The conventional definitions of spectrum analysis are discussed, as well as the principal real time spectrum analyzers.

Comments - Obviously much work went into this paper. However, apparently little interest was stimulated among the attendees.

THE NEAR FIELD NOISE OF AN OVERCHOKED AIR JET by R. Westley and J.H. Wooley (Structures and Materials Laboratory, National Aeronautical Establishment, National Research Council, Ottawa, Ontario, Canada)

Summary - The near field noise of a 2.25-in.-diameter air jet that contained shock cells was investigated over a range of nozzle pressure ratios up to 10.

Various screech frequencies were identified and the distributions of their near field sound pressure levels were plotted around the jet.

A schlieren system was used to show the positions of intense sound waves outside the jet and the positions of pressure disturbances within the flow of the jet. Modes of oscillation of the jet were photographed in slow motion using a stroboscope and a ciné camera.

Comments - The paper describes an experimental investigation of the pressure field cycle near a 2.25-inch-diameter cold-air jet, with nozzle pressure ratio of 3.1, when the jet was oscillating in the axisymmetric mode at a screech frequency of 3170 Hz. A strong source of radiation was found at the third and fourth shock cells. The near field pressure consists of partial standing waves formed by the interaction of shock cell distributed sources, flange reflections, and a convected pressure field associated with jet flow disturbances.

AIRCRAFT NOISE AT TAKE-OFF by I.P.A. Marc Pianko (STAé, Paris, France)

Summary - First, the optimum flight paths capable of minimizing aircraft noise at take-off are discussed. The determination of these flight paths brings out the aircraft parameters which (apart from engine noise) are conducive to noise at take-off. The relative influence of each parameter is calculated. The degree to which results are modified by the introduction of, for instance, duration correction, is considered. Finally, the effect of engine technology, penalties and limitations on future progress regarding noise at take-off is discussed.

Comments - This was a good mathematical treatment of optimum flight paths. It could be of interest to those planning operational procedures, such as the FAA.

AN APPLICATION OF QUADRUPOLE THEORY TO CORRELATE THE DIRECTIVITY AND SPECTRA OF HIGH SPEED JET NOISE by J.D. Voce (Rolls-Royce Limited, Bristol Engine Division, Filton, Bristol, England) and P.A. Lush (Institute of Sound and Vibration Research, Southampton University, England)

Summary - The purpose of this paper is to outline efforts being made to correlate experimental data, using Lighthill's quadrupole theory of jet noise generation with modifications due to Ffowcs-Williams for high speed flow. The early part of this work showed that a theoretical model based on a distribution of randomly oriented quadrupole sources predicts the emission angle of peak intensity and the directivity of the radiation with reasonable success, but it does not predict the spectrum behavior. Since it can be shown that the mixing region of a jet generates lateral quadrupoles with lobes aligned at 45° to the jet axis, a more complicated model can therefore be devised consisting of a distribution of lateral quadrupole superimposed upon the randomly oriented quadrupole distribution. This type of model can be used to improve the prediction of spectrum behavior and also give a better prediction of the peak intensity emission angle. However, certain discrepancies cannot be explained in terms of this model and possible reasons for this are discussed and suggestions for improvements, currently being investigated, are given.

Comments - None.

AN ANALYSIS OF SONIC BOOM REDUCTION BY ELECTRO-AERODYNAMIC AND COMBUSTION INTERACTIONS by Sin-I Cheng and Arnold Goldburg (Boeing Scientific Research Laboratories, Seattle, Washington)

Summary - Techniques to apply electro-kinetic forces and to add thermal energy to the flow field around a supersonic transport have been proposed to alter the shock configuration and thereby to reduce sonic boom. Two questions are discussed in this paper.

1. Are the techniques for reducing the boom physically valid?

2. Are the weight requirements for the electrical equipment within payload capability?

The conclusions reached are: The electro-aerodynamic and combustion techniques currently proposed are conceptually deficient. While some configurations, to be proposed in the future, of the electro-aerodynamic devices may prove to be conceptually valid, they are technically not feasible. Efforts for reduction of boom intensity should concentrate on the development of detailed optimization of the aerodynamic design of the airplane.

Comments - Using optimistic assumptions, Goldburg showed that it would take approximately 1,000,000 pounds of weight on the US SST to use electro-aerodynamic devices to reduce the sonic boom, which is impractical. No one in the audience disagreed with Goldburg's analysis.

A PRELIMINARY STUDY OF ATMOSPHERIC EFFECTS ON THE SONIC BOOM by G.A. Herbert, W.A. Hass, and J.K. Angell (ESSA Research Lab., Silver Spring, Md.)

Summary - Atmospheric effects on sonic booms generated by bomber and fighter aircraft are investigated through analysis of more than 4000 sonic-boom pressure traces obtained from a 40-microphone grid at Edwards Air Force Base, California, during the fall and winter of 1966-67. A computer program, which generates maximum overpressure values for a horizontally stratified real atmosphere, is tested against the mean observed overpressure on the grid and is shown to be in error by an average of ten percent when the maximum observed overpressure is derived from the positive impulse area. The pressure traces are grouped into 3 categories so that "spiked" signatures, which constitute the largest deviation from the mean, may be studied as a function of local weather conditions. This study shows a good correlation between depth of the surface mixed layer and the percentage of spiked signatures. The variability of the maximum overpressure also increases with increase in low-level wind speed. Both these results suggest that turbulence in the planetary boundary layer is the main cause of spiked signatures and the associated large variation in maximum overpressure. There is some evidence that waves within an inversion contribute to overpressure variability on a larger scale.

Comments - Angell made the presentation. He pointed out that actual measured overpressures were consistently less than the overpressures calculated by the two computer programs now being used by ESSA. He hypothesized that the discrepancy may possibly be due to overpressure instruments. In the discussions following the presentation, Prof. K. Oswatitsch of DVL, Aachen, postulated that the waves expanding over the microphones may cause inaccurate measurements. Angell replied that the mikes are set flush with the ground, with a wind screen to prevent unwanted triggering. Oswatitsch also questioned whether atmospheric instabilities, in addition to turbulence, may cause problems. Angell said mean values were used, and not individual boundary layers; Angell said Oswatitsch's question was valid.

SIMULATION WORK ON SONIC BOOM by C.H.E. Warren (RAE, Ministry of Technology, Farnborough, England)

Summary - None.

Comments - No abstract or pre-print was generally available at the meeting. Warren described three methods used in the UK to simulate the sonic boom. The first involves a bang from an explosive point charge, which gives a very brief modified N wave. The second involves use of linear charges, viewed on end. These give single positive and negative pulses separated in time; different size linear charges can be combined to give an overall N shape. The third involves a shock tube, with a conical section which has a diaphragm which shatters, sending an N wave down the tube. "Blunderbuss" is the name given the tube; a large facility using this approach is now being built for sonic boom simulation.

SONIC BOOM SIMULATION FACILITIES by Ira R. Schwartz (National Aeronautics and Space Administration, Washington, D.C.)

Summary - This paper discusses a broad spectrum of sonic boom simulator concepts with special emphasis on the NASA wind tunnel sonic boom techniques, the NASA Langley Low Frequency Noise Facility, the Ling Tempco Vought/NASA Shock Tube - Bursting Diaphram Facility and the General Applied Science Laboratories/NASA Quick Action-Valve Shock Tube Facility. In particular, this paper contains brief discussions of the overall design features of the facilities, their operating characteristics, their research capabilities and some research problems that are amenable to laboratory testing. The paper shows that substantial progress has been recently made in advancing the state of the art of sonic boom simulator development. Most of the requirements for sonic boom simulation and human and structural response can now be accommodated in a simple, inexpensive facility such as the General Applied Science Laboratory/NASA Quick Action-Valve Shock Tube Facility.

Comments - Schwartz said the GASL/NASA facility can incorporate realistic effects, such as near field and non-linear effects. There was much audience interest in the fact that certain results could be achieved in a chamber only 100 ft long. Schwartz noted that this can be done through use of scale effects. For example, in the GASL/NASA facility, tests can be made of both full scale and scale model phenomena where the scaling can be up to 1000:1 so that large topographical areas, e.g., on the order of one mile, can be simulated.

SONIC BOOM CONSIDERATIONS IN AIRCRAFT DESIGN by Clarence S. Howell, Armand Sigalla and Edward J. Kane (The Boeing Company, Washington)

Summary - The techniques for estimating sonic boom pressure signatures of an airplane are reviewed and the effects of different configuration variables are shown. In particular, configuration variables and novel concepts which are conducive to potentially favorable sonic boom characteristics such as low overpressure, long rise time and noncoalescence of shocks, are examined. Numerical examples illustrate the magnitude for potential improvement in sonic boom and the resulting effects on other airplane performance parameters.

Comments - Kane said that some improvement in sonic boom can result from careful attention to the lift distribution, area ruling of the fuselage, and location of the engines. Kane noted that by far the greatest configuration influences on sonic boom are wing planform and size. He said that the bound of future improvements which he projected in his presentation is based on a considerable wing loading reduction from 60 to 45 lb/ft^2, and an increase in wing slenderness causing a 40% increase in the streamwise length of the lift distribution.

NOISE CHARACTERISTICS OF THE C-5A HEAVY LOGISTICS TRANSPORT by J.A. Bair, J.Y. Yasutake and T.R. Metzler (Aeronautical Systems Division, Wright-Patterson AFB, Ohio)

Summary - The latest available noise data from the C-5A Heavy Logistics System noise measurement program will be presented. Comparisons between predicted and measured data will be included. Emphasis will be on community noise. Noise measured at ground stations during take-off and landing operations will be presented and compared to community and airport standards. Other data will be included, if available.

Comments - None.

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This report summarizes the proceedings of the AGARD meeting on "Aircraft Engine Noise and Sonic Boom", held at the French-German Research Institute, St Louis, France, 27-30 May 1969.

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