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SC-TM-144-53-51

STATE OF KNOWLEDGE IN THE GUST DESTRUCTION PROBLEM, WITH RECOMMENDATIONS FOR SANDIA CORPORATION EFFORTS.

SANDIA SYSTEMATIC DECLASSIFICATION REVIEW	
1st Review Date: 4-07-97	Determination (Circle Numbers):
Authority: ☐ADC ☒ADD	1. Classification Retained
Name: W Layn	2. Classification Changed to: U
2nd Review Date: 4/14/97	3. Contains No DOE Classified Information
Authority: ADD	4. Coordinate With:
Name: R B Craner	5. Contains UCAI?
	6. Comments: OK for Openmt

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INVENTORIED

AUG 1 1963

INVENTORIED NOV 9 '56 4101

3427-1

ABSTRACT

An extended survey of work going on through the country indicates that only token efforts are being made to determine destruction of aircraft due to effects of an atomic bomb burst, from the anti-aircraft standpoint. The present paper sets down the phenomena involved in destroying an airplane by a gust. Related, but not-directly-applicable, analyses of the escape problem are described. Specific recommendations for Sandia Corporation activity are made, which include the conduct of studies by a suitable research group (under contract) to treat the essential conditions of the destruction problem.

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Case No. 409.07

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SANDIA SYSTEMATIC DECLASSIFICATION REVIEW DOWNGRADING OR DECLASSIFICATION STAMP	
CLASSIFICATION CHANGED TO: U	AUTHORITY: R. B. Craner
Emelda Salph 4/21/97	RECORD ID: 97SN1134
PERSON CHANGING MARKING & DATE	
Carmela M Gallegos 5/5/97	
PERSON VERIFYING MARKING & DATE	DATED: 4/14/97

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State of Knowledge in the Gust Destruction Problem, with Recommendations for Sandia Corporation Efforts.

1. The purpose of this memorandum is to outline the present state of knowledge in aircraft destruction due to material velocity produced by a blast wave; and to recommend that specific tasks be performed by an appropriate research group under a contract with the Sandia Corporation.

2. SUMMARY

An extended survey* of work going on through the country indicates that only token efforts are being made to investigate destruction of aircraft (or crews) due to the four physical effects of an atomic bomb burst, i.e., gust, overpressure, thermal radiation, and nuclear radiation.

The present paper sets down the phenomena involved in a destructive situation due to gust, which include unsteady aerodynamics, rigid body response of the aircraft, flexible non-linear response of the aircraft structure, and interactions with the effects of thermal radiation and overpressure.

Related, but not-directly-applicable, analyses of the escape problem are described. These are limited to the plane of symmetry and rest on assumptions, such as linear response of the structure, which are not admissible for the destruction problem.

Finally, specific recommendations for Sandia Corporation activity are made, which include the conduct of studies by a suitable research group (under contract) to treat the essential phenomena of the destruction problem.

3. Destruction Due to Gust in Plane of Symmetry

Let us first assume that the bomb burst takes place in a vertical plane containing the plane of symmetry of the aircraft. The situation then involves the following:

a. Aerodynamic loads are produced on the aircraft by the **unsteady** aerodynamic processes which occur beginning at the time the material velocity increment is introduced by the blast wave.

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* By E. S. Rose, Jr. of WLL, and R. J. Vicars, JHU/APL.

(1) The peak loads must be expected to occur during the time that transient aerodynamic effects still predominate (based on MIT work in the bomb delivery problem). So the problem ought to be treated as essentially unsteady.

(2) The transient aerodynamic forces on an airfoil whose angle of attack is rapidly changed require a period of time to reach new steady state values. This period of time is associated with the required change of circulation and the redistribution of vortices in the flow, and may be referred to as "lift lag".

(3) The unsteady aerodynamic forces on an airfoil whose angle of attack is rapidly changed show differences in magnitude and direction from steady aerodynamic forces at the same angle of attack as the instantaneous value for the unsteady case. In particular, the unsteady case may not stall until a much higher angle of attack, and so develop a substantially higher $C_{L_{max}}$ (see Figure 1).

(4) The interaction of two lifting surfaces, e.g., wing and tail. under the condition of rapidly changing angle of attack is poorly understood. In particular, the prediction of the unsteady downwash (at the tail, due to flow about the wing) cannot be done at present.

(5) Existing methods of treating transient aerodynamic phenomena, associated with the transient forces produced by an instantaneously-introduced velocity component, do not include one characteristic of our problem, which is that a shock wave (i.e., a pressure, density, and temperature discontinuity) sweeps through the field during the time the new velocity component is being introduced.

(6) These existing methods of treatment of unsteady aerodynamics mentioned above involve one of two assumptions:

(a) The Wagner theory assumes that the new velocity component appears at all points in the field simultaneously. This condition is approximately met if the blast wave strikes the wing and tail moving in a direction essentially normal to their chord lines, so the new velocity component is introduced approximately simultaneously at all points along one side of the wing and tail.

(b) The Karman-Sears theory assumes that the aircraft flies into a semi-infinite gust field at the flight velocity. This condition is approximately met, if the blast wave strikes the wing and tail moving in a direction essentially parallel to their chord lines, and if we can introduce a new velocity of propagation of this disturbance which is not the flight velocity but the horizontal component of relative velocity between the blast wave and the aircraft.

The difference between (a) and (b) is that in (b) the gust velocity is "felt" at different times at different points along the chord lines of the wing and tail. In the present problem, there will be cases where one or the other will apply; for most, some combination of both would seem to apply. Since we are interested in all possible orientations in the plane of symmetry.

b. The aircraft can respond as a rigid body in its three symmetrical modes of motion, in response to the applied loads. Ordinarily, this rigid body motion reduces the loads experienced by the airplane.

c. The components of the aircraft structure can respond as flexible members, in the various modes of elastic (and plastic) deformation. Ordinarily, this flexible motion increases the stresses set up in the aircraft structure.

d. The aircraft structure has by this time been heated by the thermal radiation, resulting in a markedly non-uniform temperature distribution through the structure. The following situations may be encountered:

(1) Stresses may have been set up by the restrained expansion of heated members, and may still exist in considerable magnitude.

(2) The physical properties of structural components may be changed (i.e., reduced) by the elevated temperatures which now prevail.

(3) Secondary structural elements may be buckled; and the aerodynamic surface can be expected to be buckled, and at high temperature with respect to the surrounding air, which may effect the aerodynamic forces developed.

e. Over the time interval that the aircraft is subjected to the material velocity, it is also subjected to the overpressure loading,

which may influence the rigid body motion, the flexible response, and the state of stress in structural elements.

f. The response of the structure is essentially non-linear (say in the load-deflection sense), since we are interested in carrying the loading process to failure. This non-linearity arises from two causes:

(1) Taking materials into the non-linear range.

(2) Failure of the highly-redundant structure can be expected to take place by the failure of some element(s), with a redistribution of load, failure of some other element(s), etc.

g. Finally, because we are intent on producing failure, the possibility that the structure will completely fail in some area, alleviating loads on more essential sections while not wrecking the airplane, must be taken into account. An example would be failure at some wing station fairly far out along the spar, resulting in loss of wing from that station to the tip, but still allowing the aircraft to limp to the target.

4. Considerations Which Argue Against a Highly-Precise Determination of Destruction Envelopes

In order to establish a realistic frame of reference, the following are introduced:

a. Our targets are enemy aircraft. With the apparently limited information now available to our intelligence agencies, very little of the detailed structural information we would like to have seems to be forthcoming. The TU-4 may be a lone exception*, but it does presently seem to be the prime threat.

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* There seems to be a strong likelihood that the TU-4 airframe is a "rivet-by-rivet" copy of the early version of the B-29 which fe[illegible] into Russian hands during WWII. Intelligence agencies ought to be asked this question - so far, this has not been done. The various people the author has talked to have been split about 50-50 between, "I think so," and "I don't know". The short time between B-29 capture and TU-4 unveiling (2-3 years) may be the clue, but this all ought to be investigated.

b. The uses foreseen by the author for the destruction studies all imply that they will be inputs to probabilistic studies, for which the geometry of the actual destruction envelope will be approximated by some simpler geometric shape, like a cylinder, sphere, or stack of disks.

Parenthetically, notice should be taken that three major air defense guided missile projects*, now under development, apparently intend to employ atomic warheads, at least as one warhead option. It appears to the author that the total usefulness of the destruction studies is greatest before the decision to undertake a development program has been reached; and declines as the missile and the warhead go through development, OST, tactical deployment, and operational employment. This observation, if generally accepted, may guide us in the relative effort to be put into interim destruction studies, and long range efforts aimed at more precise (and more reliable) results.

5. Applicable Analysis

The only gust work done to date believed to have any real significance is the gust analysis of the escape problem by MIT**. They have completed an elegant analysis of the plane of symmetry escape problem which includes:

a. Treatment of unsteady aerodynamics by Wagner function.

b. Rigid body motion of aircraft in pitch and vertical translation (change in ground speed assumed zero).

c. First two elastic modes of wing.

This analysis has the following limitations:

a. Differences between unsteady values of $C_{L_{max}}$ and steady values of $C_{L_{max}}$ are not accounted for. They use the steady value of $\frac{dC_L}{d\alpha}$.

b. The aerodynamic loads, as a function of α, represent a linearized approximation to the actual variation.

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* Talos-N, Nike-B, and Bomarc.

** The Aero-Elastic and Structures Research Laboratory of MIT, under the direction of Professor R. L. Bisplinghoff and Professor H. G. Stever, has worked on this problem since July, 1949 under AF Contract No. AF33(038)-3006, RDO 451-368. This contract is monitored by the Aircraft Lab, WADC (Mr. F. Janik, Jr.). MIT has written WADC Tech Report 52-244, Vols. I thru VII, on the escape problem.

c. Unsteady interaction between wing and tail are not taken into account.

d. Effect on aerodynamic forces of the shock wave sweeping the field is not included.

e. Acceleration of the aircraft in a direction parallel to the direction of flight, in an inertial reference, is assumed zero. This might be stated, the ground speed remains constant, but not the airspeed. This assumption is believed sound for destruction studies also.

f. Superposition of gust and thermal effects is not done.

g. Superposition of gust and overpressure effects is not done.

h. Non-linear response of the structure, which is outside the range of interest for the escape problem, is not examined.

i. Prediction of failure in one location instead of another, also out of range of interest for escape problem, is not considered.

Under the assumptions implied by the above, the MIT group writes the equations of motion for the aircraft exposed to the material velocity. These general equations are sufficiently involved (i.e., a system of j + 2 simultaneous linear integro-differential equations, where j is the number of flexible modes considered) that solution requires the use of a computer like the REAC.

6. Simplified Method

The next step is to look for additional simplification which can be made The following simplifications are first examined and then adopted.

a. The fuselage is restrained in pitch for the determination of mode shapes and frequencies of the wing.

b. The pitching degree of freedom is discarded in the simplified equations of motion.

c. Aeroelastic effects are neglected. (The authors separate aeroelastic effects into the aerodynamic loads which act on the "r^{th}" mode as a result of flexible motion in all other modes, which they call "coupling"; and the aerodynamic loads which act on the "r^{th}" mode as a result of flexible motion in the "r^{th}" mode, which they call "damping". The study examines the conditions under which each can be neglected. Since these terms couple the equations of motion and thus necessitate simultaneous solution, neglecting them produces a substantial simplification.)

These simplifications lead to equations which can be solved by use of a desk calculator. However, the solution is far from simple and entails a considerable amount of computational labor.

7. Semi-Graphical Approximation to Simplified Analysis

The possibility of a semi-graphical approximation to the simplified analysis apparently arose from noting that in the simplified equations, expressions occurred which were the product of a function of the dimensionless aircraft mass parameter K (see footnote) and the dimensionless time variable s_o', and an expression which is the result obtained using the sharp edged gust solution (that is, the aerodynamically quasi-steady, rigid stationary aircraft solution). The approach was then to consider this function of K and s_o' as an "alleviation factor" to be applied to the load given by the sharp edged gust expression. The alleviation factor F is presented graphically as a function of s_o' for parametric values of K.

The above determination of the peak value of the applied load permits an expression to be written for the forcing function. The response of the flexible structure remains to be determined. Vols. III and VII of WADC Report 52-244 outline the method of calculation amenable to use of a desk calculator.

8. Comparison of Three Methods

On pages 286 to 292 of WADC TR 52-244, Vol. III, comparison is made between the general method, the simplified method, and the semi-graphical approximation to the simplified method. The maximum spread in peak values of vertical acceleration at the CG is about 3%. The maximum spread in peak values of wing displacement is about 11%. Solutions compared are for the T-33 aircraft.

Footnote

$$K = \frac{\rho (c)^2}{m} C_{L_{\alpha_A}}$$

where

ρ = air density

c = mean geometric chord

m = airplane mass/span

$C_{L_{\alpha_A}} = \left.\frac{dC_L}{d\alpha}\right]_{airplane}$

$$s_o' = \frac{2U' t_o}{c}$$

where

U' = Approximate velocity of air relative to lifting surface

t_o = time duration of material velocity positive phase, sec.

9. Hobbs Approximation

Mr. Norman Hobbs, of the MIT group, has written a brief un-titled paper which presents a simple statement of the last-mentioned method above. In applying this approach for a destruction study, the actual ultimate load factor for the particular aircraft member in question must be used, to assure failure. Hobbs suggests the additional approximation of using an "average" value of 0.80 for the alleviation factor F.

In applying this approach to a few quick-and-dirty destruction studies done by WADC for Project Heavenbound*, a further approximation was made. It was noted that an "average" value of the dynamic overstress factor D_K is about 1.5, and this enters only as the product of $D_K \times F$. An "average" value of the alleviation factor F is 0.80. So this "average" product is 1.2; WADC assumed it to be unity, justifying it on the basis that actual ultimate strengths are usually 1.0 to 1.1 times the design ultimate. The difference between these numbers and 1.2 is a safety allowance.

10. What Should be Done Now

a. The Sandia Corporation program should consist of two separate (but coordinated) efforts as follows:

(1) Interim gust destruction information should be developed by the Corporation with or without contractor assistance.

(2) A long-range project to provide more adequate treatment of the gust destruction problem should be undertaken by a suitable contractor to the Sandia Corporation. University groups are considered appropriate for this effort. A partial list of potential contractors would include:

(a) MIT, Aero-Elastic and Structures Research Laboratory

(b) Defense Research Laboratory (University of Texas)

(c) California Institute of Technology

(d) New York University

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* A feasibility study of the use of atomic warheads as anti-aircraft devices by ARDC of USAF. Chief responsibility rests on SWC; project officer is Maj. Travis Scott. Major emphasis has been on delivery means, accuracy, etc.

(3) Some parts of the long-range project may be capable of being treated by a single advanced investigator, on a consultant basis. Professor M. V. Barton of the University of Texas is known to be interested in the problem.

The tasks to be performed in sequence by a contractor as the long-range effort are outlined in b. and c. below.

b. Plane of Symmetry

At present the only rigorous analysis of the effects on an aircraft of a gust due to an atomic bomb burst is restricted to the escape problem, with the bomb burst in the plane of symmetry. This analysis is not presently adequate to treat the destruction problem. In order to extend this analysis to the destruction problem, in the plane of symmetry, certain important differences must be taken into account.

(1) Non-linear response of the aircraft structure. should be introduced first. For this first refinement, it seems permissible to use either rigid body applied loads, or applied loads including aero-elastic contributions for a linearly-responding structure.

(2) The second refinement (which may be done independently) is to investigate whether failure in some less critical section (say far out along the wing span) will significantly affect the loads we wish to produce at the more critical section (say, at or near wing root).

(3) The third refinement desired is to improve the determination of the applied loads. This might include:

(a) Aero-elastic contributions for the non-linear structure.

(b) Removal of the linearizing restrictions made in calculating the aerodynamic loads.

(c) Treat the essential differences between unsteady and steady flow at high angles, such as "stall-overshoot".

(d) Improve the treatment of the time history of lift due to gust (beyond use of Wagner function).

(4) Finally, as progress is made in the study of effects of thermal radiation and overpressure, an effort should be made to superimpose effects of gust, thermal radiation, and overpressure.

The first two steps recommended above are called out with much more confidence than the last two. As we proceed into the problem, it is quite possible that our ideas on these latter steps will change.

b. Outside the Plane of Symmetry

(1) The first step is to determine the rigid body response of the aircraft to a gust component normal to the plane of symmetry Treating the aircraft response as a perturbation, the longitudinal (i.e., symmetrical) and lateral (asymmetrical) responses may be superposed.

(2) Then, gust loads based on rigid body response to the gust should be calculated.

(3) These gust loads should be applied first to the structure assuming a linear response of the structure; and finally to the structure assuming a non-linear response, to determine the stresses produced.

(4) Finally, the sort of refinements mentioned above (in b. (2), (3) or (4)) may be introduced.

11. The undersigned wishes to express his appreciation to Dr. M. V. Barton, whose judgment and experience were of great help in preparing this paper.

E. S. ROSE, JR. - 5141

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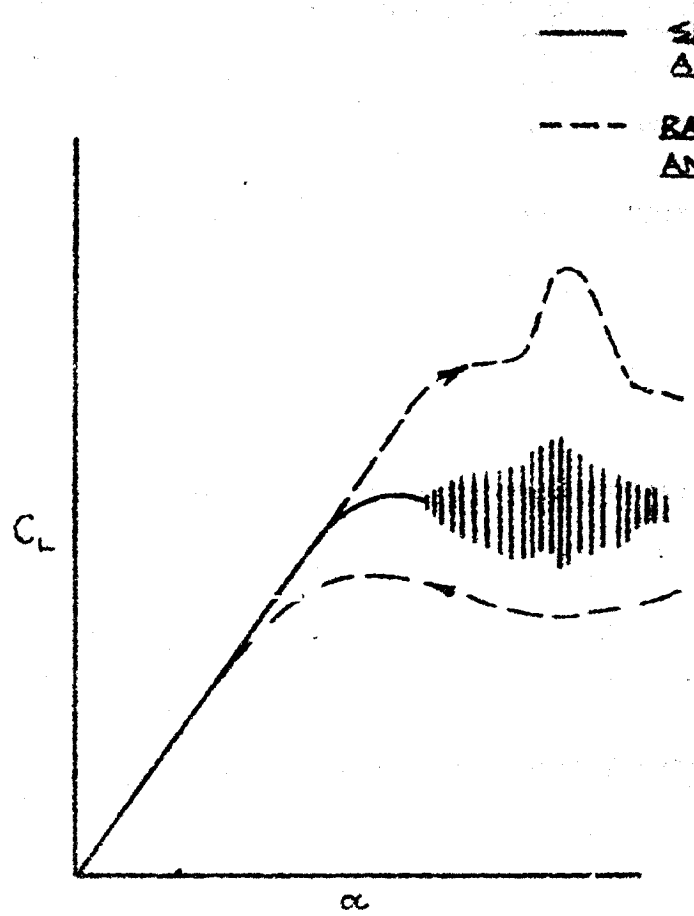

"STALL-OVERSHOOT" - A difference in airfoil behavior depending upon the time rate of change of angle of attack.

Ref: Goldstein, Vol. II, p 472

Note: The vertical shading indicates fluctuating values of C_L.

[redacted]

Figure 1