International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 37 العدد
Part 1 المجلد

http://www.doi.org/10.62341/aker0714

Received	2025/06/15	تم استلام الورقة العلمية في
Accepted	2025/07/13	تم قبول الورقة العلمية في
Published	2025/07/14	تم نشر الورقة العلمية في

Effects of AGM-65B Maverick Cruise Missile's Mass on Its Path Performance.

ALI KHALIFA ELRATAIMI
EMAIL : ALIELRATAIMI@GMAIL.COM
ZAWIA HIGHER INSTITUTE OF SCIENCE AND TECHNOLOGY
ZAWIA- LIBYA

ABSTRACT

This paper presents an analysis of the trajectory for the AGM-65B Maverick missile. The missile's performance is governed by the equations of motion, which are fundamental to understanding its dynamics. This work offers a detailed analysis of the flight dynamics for the AGM-65B missile. It concludes that, while solving the governing equations is relatively straightforward, obtaining accurate aerodynamic data and the missile's mass and inertia properties poses a greater challenge. The study focuses on the path of an air-to-surface missile attacking a fixed target. The missile is required to strike the target from above, adhering to the missile's dynamic and trajectory constraints. The problem is approached using optimal control theory, leading to the formulation of a minimum integrated altitude trajectory. This formulation incorporates nonlinear, three-dimensional missile flight dynamics, along with specific boundary conditions and path constraints. The resulting optimal trajectory provides insight into how the range, altitude, and lateral deflection (Y-axis) vary over time. The trajectory is computed numerically using a computer code that calculates the missile's position at any given time.

Keyword: Path , Missile , Wing , mass , Velocity, Thrust , Drag , Lift , Angle of attack , Altitude , Force, Distance .

http://www.doi.org/10.62341/aker0714

تأثير كتلة صاروخ كروز نوع AGM-65B MAVERICK على كفاءة مساره

علي خليفة الرتيمي
قسم الهندسة الميكانيكية
المعهد العالي للعلوم والتقنية – الزاوية- ليبيا
ALIELRATAIMI@GMAIL.COM

الملخص

تقدم هذه الورقة تحليلاً لمسار صاروخ **AGM-65B Maverick** يخضع أداء الصاروخ لمعادلات الحركة، والتي تُعد أساسية لفهم ديناميكيته. يقدم هذا العمل تحليلاً مفصلاً لديناميكا الطيران لصاروخ **AGM-65B** و رغم أن حل المعادلات الحاكمة أمر مباشر نسبياً، إلا أن الحصول على بيانات أيروديناميكية دقيقة وخصائص الكتلة والقصور الذاتي للصاروخ
يمثل تحدياً أكبر.

تركز الدراسة على مسار صاروخ جو- أرض يهاجم هدفاً ثابتاً. غلى الصاروخ ان يصيب الهدف من الأعلى مع الالتزام بقيود ديناميكا ومسار الصاروخ

تم تناول المشكلة باستخدام نظرية التحكم الأمثل، مما أدى إلى صياغة المسار بارتفاع متكامل. تتضمن هذه الصياغة ديناميكا طيران الصاروخ غير الخطية ثلاثية الأبعاد، إلى جانب شروط حدودية وقيود مسار محددة.

يوفر المسار الأمثل الناتج فهماً لكيفية تغير المدى والارتفاع والانحراف الجانبي (محور Y) مع مرور الوقت

يتم حساب المسار عددياً باستخدام برنامج حاسوبي يحسب موقع الصاروخ في أي لحظة زمني.

الكلمات المفتاحية: المسار، الصاروخ، الجناح، الكتلة، السرعة، الدفع، السحب، الرفع، زاوية الهجوم، الارتفاع، القوة، المسافة.

INTRODECTION.

As an unmanned flying vehicle, a missile must have the capability to control its flight path, compensating for any disturbances encountered during flight. The flight control system, which is

http://www.doi.org/10.62341/aker0714

computer software, requires accurate aerodynamic data specific to the missile. This data is essential for developing the flight mechanisms that control the missile. The flight control system can be viewed as a problem of solving the equations of motion. During the development phase, it is crucial to create a computer code that solves these equations based on the missile's aerodynamic characteristics, control surface movements, and mass and inertia properties. This allows for the prediction of the missile's trajectory and velocity at any given moment.

2. The Objective of Present Works

The flight dynamics equations form a comprehensive system that describes the missile's performance under various flight conditions. The goal of this present work is to solve these equations of motion to obtain the state-space variables. By developing a computer code, this work aims to provide a tool for accurately estimating the missile's flight performance. An example of good missile may the AGM 65B Maverick Cruise Missile, which the brief description about this missile is given in the following sub chapter.

3. Short Description AGM-65B Maverick Cruise Missile.

The AGM-65 Maverick is a tactical air-to-surface missile, guided by either infrared or electro-optical sensors. While it is primarily used for Close Air Support missions, the Maverick is also highly effective in anti-armor, Suppression of Enemy Air Defences (SEAD), and interdiction roles. The AGM-65 Maverick program was initiated in 1965 in response to the poor performance of the command-guided Bullpup missile during the Vietnam War. In June 1968, Honeywell was awarded the production contract after a competitive process against Rockwell. The Maverick's key features include its compact design, which allows for multiple missiles to be carried, its autonomous guidance system, and a high Probability of Kill (Pk). Initial unguided test flights began in September 1969, and AGM-65A Mavericks have since been successfully launched from altitudes as low as treetop level. Figure 1. Shows how this missile configuration look likes while Table 1 describe the pertinent missile dimension and performance adopted from Re. 1.

http://www.doi.org/10.62341/aker0714

Figure 1: AGM-65B MAVERICK Cruise Missile

Table 1: AGM-65 Specifications [1]

Missiles	AGM-65B Maverick
Length ,m	2.49
Diameter , m	0.3
Weight , kg	304
Operational range ,km	22
Wingspan , m	0.710
Target approach flight level ,m	About 5
flight speed , kmph	1150
Warhead weight , kg	57

4. Mathematical model Missile Performance

Assume that each rocket is designed to be a solid with a constant mass density and is symmetric about the X-Z plane in the body axes. The forces and moments acting on the aircraft were derived from aerodynamics, thrust, and gravity. Assume that thrust acts along the X axis of the body and through the center of gravity. Assume a constant atmosphere, with aircraft flying limited to altitudes below 50,000 feet and speeds subsonic. The curvature of the Earth is neglected, and it is assumed that the Earth is stationary in space due to inertia, thus the axes of the Earth were considered inertia axes. Assume a uniform gravitational field, so that the center of mass and In this model, each missile is considered a rigid body with constant mass density and symmetry about the X-Z plane in the body axes. The forces and moments acting on the missile arise from aerodynamics, propulsion, and gravity. The thrust is assumed to act along the X body-axis and pass through the center of gravity. A stationary atmosphere is assumed, with flight restricted to altitudes below 50,000 feet and subsonic speeds. The Earth's curvature is neglected, and the Earth is considered fixed in inertial space, treating the Earth axes as inertial axes. The gravity field is assumed uniform, with the center of mass and the center of gravity coinciding, resulting in no gravity-induced moments or changes in gravity with altitude.

International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 37 العدد
Part 1 المجلد

http://www.doi.org/10.62341/aker0714

To develop the equations of motion, two coordinate systems are defined. The first is a fixed coordinate system with its origin on the Earth, and the second is a coordinate system attached to the missile, commonly referred to as the body-axis system. Figure 2 show the set up coordinates system that applied to the missile model.

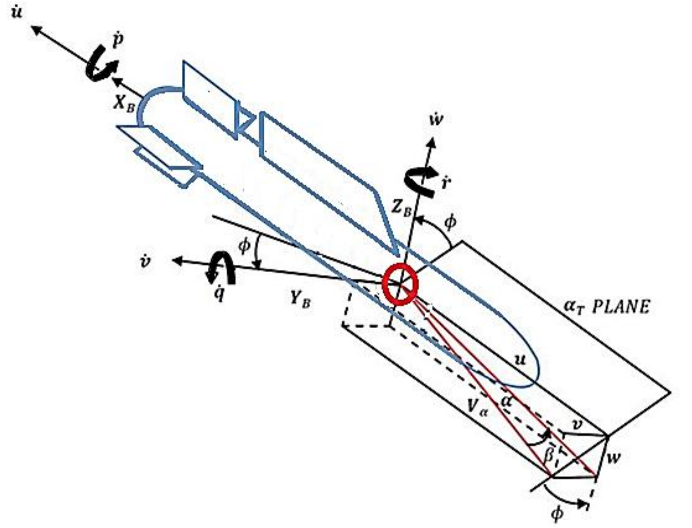


Figure 2: Six-degree-of-freedom motion of Cruise Missile [4]

The missile's motion is modeled as a fully nonlinear, six-degree-of-freedom rigid body, encompassing both translational and rotational movements. This model neglects the relative motion of internal components, structural distortion, and the sloshing of liquid fuel. However, gyroscopic effects due to rotating engine turbo machinery are included in some cases. Standard conventions are followed, where missile rotation adheres to the right-hand rule, and control surface deflections follow a sign convention where the fingers curl in the direction of positive deflection when the thumb points along the control surface hinge line in the direction of a positive body axis.

If the missile mass m and the vector velocity of the aircraft with respect to earth axis coordinate $\overrightarrow{V_p}$, which if written in term of their component velocity to the system xyz is:

$$\overrightarrow{V_p} \;=\; Ui + Vj + Wk\,, \tag{1}$$

While in term of system the velocity vector $\overrightarrow{V_p}$ is:

$$\overrightarrow{V_p} \;=\; ui + vj + wk\,, \tag{2}$$

http://www.doi.org/10.62341/aker0714

In respect to inertial axis, the Newton's second law can be applied to formulate the governing equation of flight motion. Detail how to derive the equations of motion can be obtained [2] Their result can be concluded that the equation of motion in six degree of freedom can be given as:

$$F_x = m(\dot{u}^E + qw^E - rv^E) \tag{3}$$

$$F_y = m(\dot{v}^E + ru^E - pw^E) \tag{4}$$

$$F_z = m(\dot{w}^E + pv^E - qu^E) \tag{5}$$

In above equation F_x, F_y and F_z are the components of the external applied forces, while M_x, M_y and M_z are the components of the external applied moments. The angular velocities in these equations are in radians per second.

$$\mathrm{p} = \dot{\phi} - \dot{\psi} \sin\theta \tag{6}$$

$$\mathrm{q} = \dot{\theta}\cos\phi - \dot{\psi}\cos\theta\sin\phi \tag{7}$$

$$\mathrm{r} = \dot{\psi}\cos\theta\cos\phi - \dot{\theta}\sin\phi \tag{8}$$

The equations presented above are just a subset of the many equations used in the program. They are quite general and rest on a few key assumptions: First, the airplane is modeled as a rigid body, which may have attached to it any number of rigid spinning rotors. Second, the X-Z plane is assumed to be a plane of mirror symmetry. Lastly, the axes of any spinning rotors are fixed relative to the body axes, with the rotors maintaining a constant angular speed relative to the body axes. The system of equations consists of fifteen coupled nonlinear ordinary differential equations in the independent variable ttt, along with three algebraic equations.

To accurately determine the dependent variables, it is first necessary to study the aerodynamic dynamic forces (X, Y, Z) and moments (L, M, N). It is clear that these forces and moments are affected by the relative motion of the aircraft with respect to the air, which is characterized by the linear and angular velocities (V and ω), in addition to the control variables that define the angles of any moving surfaces and the settings of any thrust controls that determine the thrust vector. Thus, it is universally accepted in flight dynamics that the six forces and moments are functions of

http://www.doi.org/10.62341/aker0714

the six linear and angular velocities (u, v, w, p, q, r) and the control vector

5. Discussion and Result

A computer code based a Fortran 77 program language had been developed. This program was designed able to calculate flight trajectories with the rotary dynamics and changing the centre of gravity are neglected. The Flight-path or flight trajectories program which often called Flight Path program, is useful in the early design stage, to assess feasibility and performance limitations of missile design. Using the data geometry as depicted in Figure 1, and Table 1.

Table 1. Missile's parameters[1]

SYMBOL	SW	BW	AG	MASS	VEL	THR
VALUE	1.333	2.0	32.2	20.83	843.9	56.0

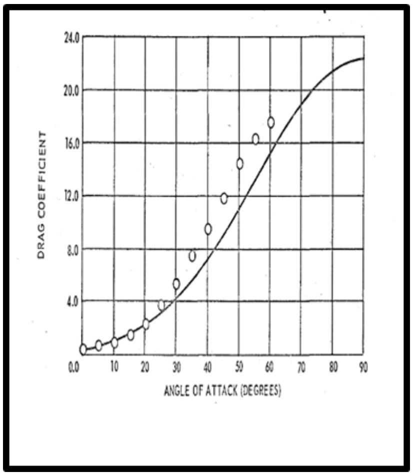
AG - Acceleration of gravity
Bw - Wing span, or reference length
SW - Wing or reference area
VEL - Velocity
THR - Thrust

The aerodynamics characteristics in term of lift coefficient C_L and drag coefficient C_D as function angle of attack by using Computer Code called PERFORM been found as given in Table 2 or Figure 2. which showing the plot of C_D versus angle of attack and Figure 3 for the plot of C_L versus angle of attack .

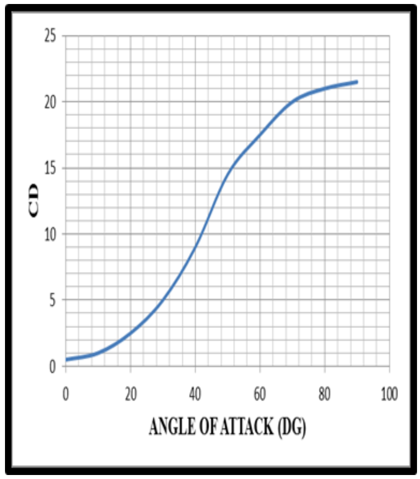
Table 2 Aerodynamic Characteristic Missile

NO	ALPH,DG	C_L	C_D
1	0	0	0.5
2	10	1.8	1
3	20	5.5	2.5
4	30	9	5
5	40	11.5	9
6	50	12.5	14.5
7	60	11.75	17.5
8	70	9.5	20
9	80	5	21
10	90	0	21.5

http://www.doi.org/10.62341/aker0714

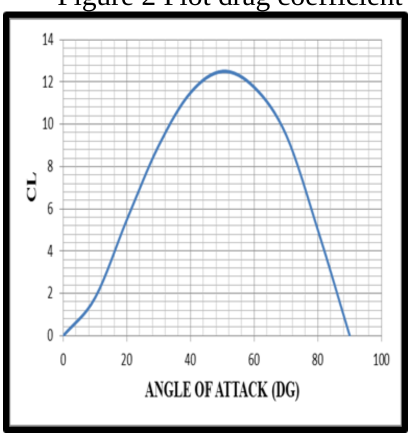


TYPICAL [3]

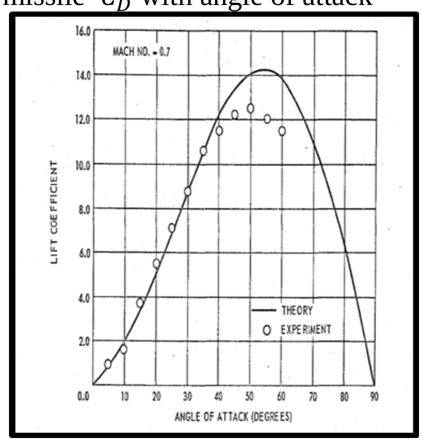


AGM-65B

Figure 2 Plot drag coefficient of missile C_D with angle of attack



AGM-65B



TYPICAL [3]

Figure 3: Plot of lift coefficient missile C_L with angle of attack
Through those two figures indicate the PERFORM code as the tool for evaluating the aerodynamics characteristics missile able to produce the result as typical missile aerodynamics

The total mass of missile is very important factor that effects on its path, where the position of the missile it will change with mass that's mean the altitude and range and Y-axes deflection will change with any change of it . In this case three different values of missile mass are selected, they are namely $M_1 = 20.83, M_2 = 30.83$ and $M3 = 10.83$. Using the Path Performance Code, how the mass give influence to the trajectory in x, y and z direction

http://www.doi.org/10.62341/aker0714

as shown in Figure 4, 5 and 6 respectively . While figure 7 show their result the plot is carried between altitude and x-distance

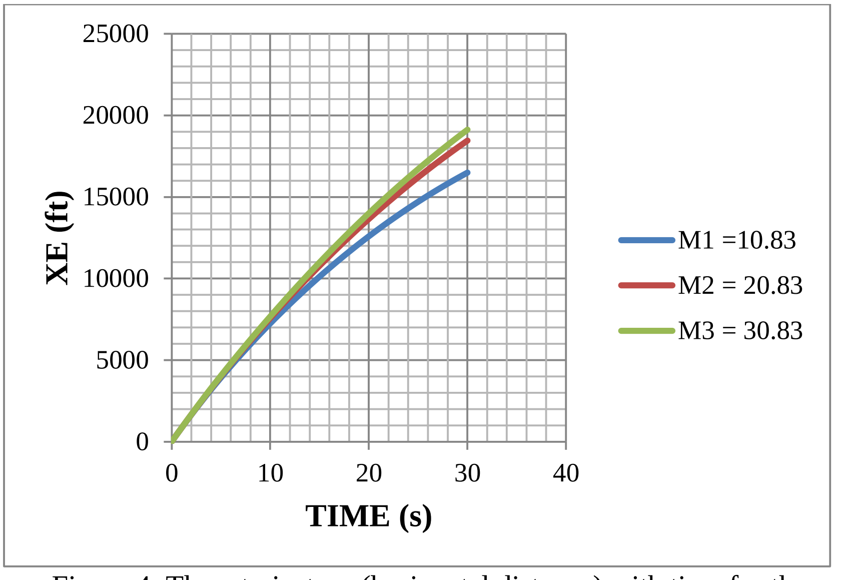


Figure 4: The x trajectory (horizontal distance) with time for three different missile mass.

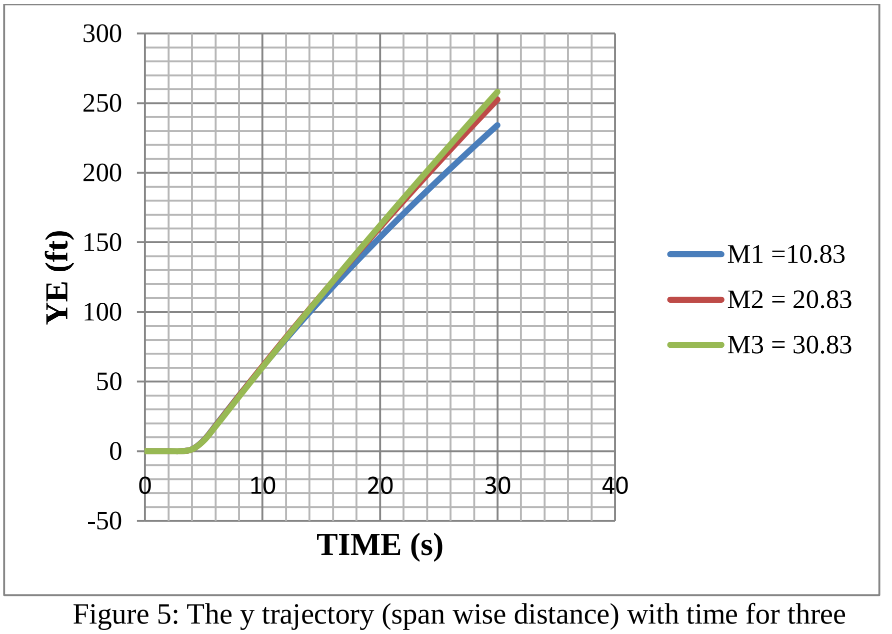


Figure 5: The y trajectory (span wise distance) with time for three different missile mass.

http://www.doi.org/10.62341/aker0714

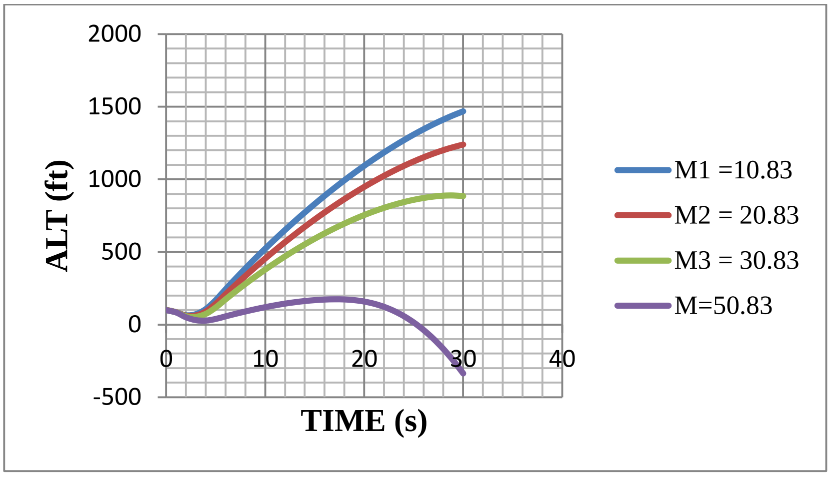


Figure 6: The y trajectory (altitude distance) with time for three different missile mass.

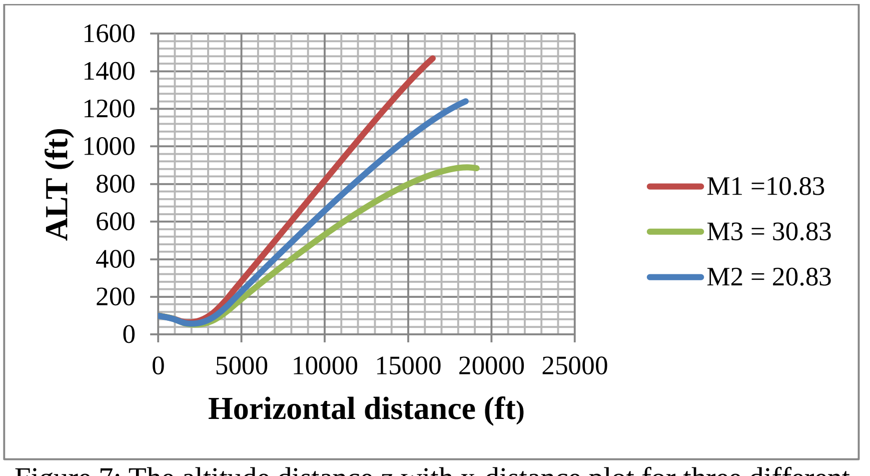


Figure 7: The altitude distance z with x-distance plot for three different missile mass

Conclusion

Considering to the result, it showed that the mass and location of missile center of gravity determine the overall trajectory of the missile. Analyzing the missile trajectory through the developed computer code it had been found the following facts

The mass and location of missile center of gravity also determine the overall trajectory of the missile. Analyzing the missile trajectory through the developed computer code it had been found the following facts.

The mass of missile so plays important role in determining missile's trajectory. The current aerodynamics characteristics

http://www.doi.org/10.62341/aker0714

which had been applied in the present trajectory's missile analysis had found that the increasing mass of the missile had made the missile movement in the y – direction but the movement in z direction which related to the missile altitude tends to the down direction mass may need to be done firstly in the future work in order be able to evaluate appropriately the developed computer code capability.

REFERENCES

[1] https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104577/agm-65-maverick/
[2] MALCOLM J. ABZUG "Computational Flight Dynamics" - AIAA Education Series 1998.
[3] "Method For 'Predicting The Static Aerodynamic Characteristics Of Typical Missile" Naval Ship Research And Development Center.
[4] Aliyu Bhar Kisabo and Aliyu Funmilayo Adebimpe "State-Space Modeling of a Rocket for Optimal Control System Design, in book Ballistics ,editor : Charles Osheku, 2019
[5] R.H._Barnard, D.R. Philpott,_A.C. "Mechanics of Flight" 11th edition
[6] John_H._Blakelocka"Automatic_Control_of_Aircraft" Second Edition.
[7] Zak Sarris "Survey of Uav Applications in Civil Markets (june 2001) ", STN ATLAS-3 Sigma AE and Technical University of Crete, Crete, Greece, 2001
[8] George_M._Siouris_"Missile_Guidance_and_Control"
[9] http://www.brahmos.com/index.php
[10] P. K. Menno* and E. J. Ohlmeyer "Integrated Design of Agile Missile Guidance and Control Systems" (science direct) 1999
[11] Alex Sullivan "Aerodynamic forces acting on an airfoil" Physics Department; The College of Wooster; Wooster; Ohio; 44691; USA May 6, 2010.
[12] http://www.aerospaceweb.org/question/weapons/q0158.shtml