Acoustics • Shock • Vibration • Signal Processing **January 2003 Newsletter**

Akemashite Omedeto Gozaimasu

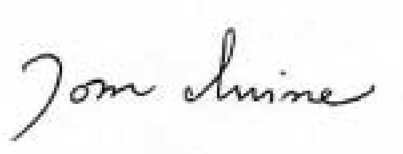
One of my career opportunities is to analyze the random vibration environment experienced by rocket vehicles as they accelerate past the speed of sound and encounter the maximum dynamic pressure condition. The formation of shock waves and turbulent boundary layers are the main sources of the vibration.

This month's newsletter gives an article that explains some of the basic principles of this aerodynamic buffeting with respect to both vibration and control stability. Chuck Yeager's historic flight in the X-1 aircraft is used as an example.

The second article gives a somewhat whimsical account of vibration as used as a plot element in three TV sitcom episodes.

I wish everyone health, happiness, and prosperity throughout the New Year.

Sincerely,



Tom Irvine
Email: tomirvine@aol.com

Feature Articles

WELCOME TO VIBRATIONDATA

SHOCK & VIBRATION CD OFFER

The Vibrationdata CD contains over 100 tutorial papers, as well as NASA and military handbooks.

Topics include

- Acoustics
- Pyrotechnic Shock
- Shock Response Spectrum
- Random Vibration
- Signal Processing
- Dynamic Data Acquisition and Analysis
- Modal Testing
- Finite Element Methods
- Structural Dynamics
- Earthquake Engineering

The CD also contains: Arthur W. Leissa, NASA SP-160, Vibration of Plates

The price for the CD is $80.00 (US).

To order, please send a check or money order to:

Tom Irvine
Vibrationdata
2445 S. Catarina
Mesa, Arizona
USA 85202

Payment via PayPal is also accepted.

Aerodynamic Buffeting at Transonic Speeds By Tom Irvine

Historical Background

P-47s, P-51s, and other World War II aircraft flew at speeds up to 80% of the speed of sound, or Mach 0.8. These aircraft had very thick wings and large canopies. As a result, the airflow along the wings and canopies had to travel a greater distance than the air along the smoother surfaces of the fuselage. The local airflow along the wing top surfaces could thus approach the speed of sound, or Mach 1.0, even though the aircraft speed was Mach 0.8.

Aerodynamic shock waves formed along the wings and canopies when the local airflow approached the transonic condition.

A shock wave represents an increase in "entropy," in thermodynamic terminology. Viscous and thermal conduction effects within the wave render the process "irreversible."

The shock waves forming on an aircraft had the potential to cause a loss of stability and control. Furthermore, the airflow behind the shock waves could be a very turbulent, separated flow, as shown in Figure 1.

The shock waves and turbulent airflow resulted in buffeting and structural vibration.

A number of aircraft crashed during the war due to aerodynamic instability and buffeting. An aircraft was particularly vulnerable if it were in a high-speed dive, in which case the speed of the entire aircraft could approach the speed of sound. Some of these aircraft likely surpassed Mach 1 but were destroyed in the process.

Captain Chuck Yeager is considered to be the first pilot to "break the sound barrier." He achieved this while flying the Bell X-1 research aircraft in 1947.

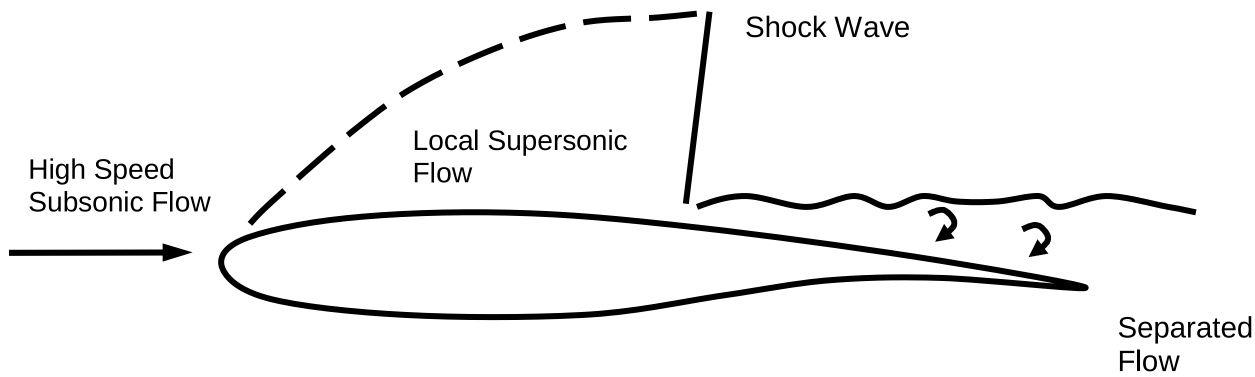


Figure 1. Schematic of Shock-Induced Separated Flow (Freestream Mach Number 0.80 to 0.99)

The separated flow over the top surface of the airfoil is caused by the presence of a shock wave. The shock wave interacts with the thin, friction-dominated boundary layer adjacent to the surface of the airfoil. This causes the boundary layer to separate in the region where the shock impinges on the surface. A massive region of separated flow trails downstream, greatly increasing the drag and decreasing the lift. The separated flow region was called a "compressibility burble" in NACA technical reports. NACA is the acronym for National Advisory Committee for Aeronautics. It was the forerunner of NASA. For reference, a diagram showing supersonic flow is shown in Figure 2.

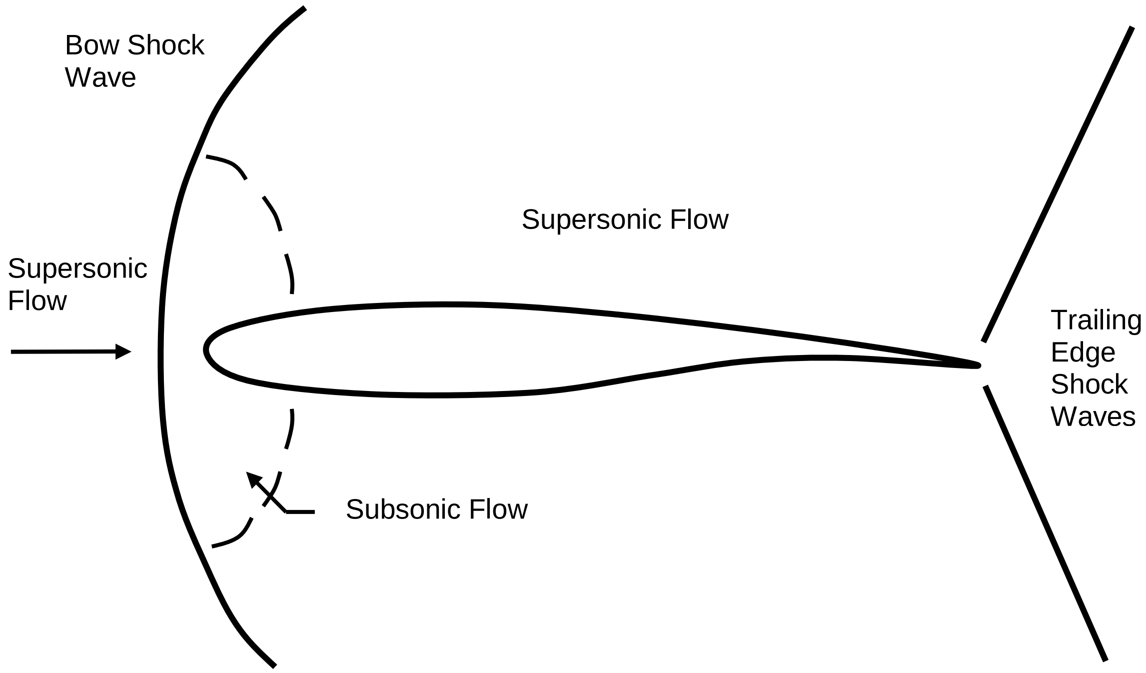


Figure 2. Schematic of Supersonic Flow (Freestream Mach number from 1.0 to about 1.2)

A bow shock forms in front of the leading edge. Shock waves also form at the trailing edge.

Bell X-1 Design

Designing an aircraft that could fly safely at supersonic speeds was a goal of both the U.S. and the Soviet Union in the years following World War II. The two nations were competing against one another for air superiority in what became the Cold War.

The U.S. Army Air Corps led a contract with Bell Aircraft Company to build a research rocket-powered aircraft called the X-1, which is also known as the XS-1. This bullet-shaped aircraft had very thin wings so that it could fly faster before it ran into the buffeting problems.

The XLR-11 rocket engine provided the X-1 with 6,000 pounds of thrust. It was fueled by a mixture of liquid oxygen and ethyl alcohol.

Furthermore, the rocket engines allowed the aircraft full thrust at altitude. In contrast, jet engines decrease in thrust at higher altitudes.

Structural integrity was also an important design parameter. World War II aircraft were typically designed to withstand loads of 7.3 G, or 7.3 times the pull of gravity. Higher loads could cause the wings to snap off, or provoke other failure modes. The X-1 was designed for loads of 18 G, however.

Initially, the X-1 had elevators for control. A design change was made to give the X-1 a moveable, horizontal stabilizer, however, after several early subsonic flights.

The X-1 was launched from underneath a modified B-29, which was a large four-engine aircraft.

The test flights took place above Muroc Dry Lake, a large expanse of flat, hard lake bed in California's Mojave Desert. This test range is now part of Edwards Air Force Base.

Bell X-1 Early Flights

Captain Chuck Yeager was the test pilot chosen to fly the Bell X-1. He was a veteran P-51 pilot from World War II.

Yeager pushed the X-1 from Mach 0.80 to 0.94 during the early test flights, but the aircraft began buffeting and as he approached Mach 1.

In addition, the pitch control became unresponsive, because a shock wave had formed on the elevator. Yeager was thus unable to change the pitch angle, or to raise or lower the aircraft's nose in flight.

Captain Jack Ridley was the project engineer. Ridley solved the control problem by modifying the X-1 with a moveable, horizontal stabilizer, as mentioned previously. Ridley's "flying tail" concept was eventually incorporated into all supersonic aircraft.

Bell X-1 Supersonic Flight

Yeager made his historic supersonic flight on October 14, 1947.

Yeager had been thrown by a horse the previous day, injuring his ribs. He avoided telling anyone of his injury, however, because he was determined to complete his mission.

The B-29 carried the X-1 to an altitude of 7000 feet, whereupon Yeager climbed down through the bomb-bay into the X-1.

The B-29 went into a dive at 26,000 feet. It then pulled up and launched the X-1, with an initial speed of 250 mph.

The X-1 rocket engines then ignited, propelling the aircraft upward at a 45° angle. Aerodynamic shock diamonds appeared in the trailing exhaust jet, as shown in Figure 3.

The advantage of the upward trajectory is that the speed of sound decreases with

Figure 3. Bell X-1 with Diamond Shock Waves in Exhaust Trail

altitude, thus the speed required to achieve Mach 1 is lower at higher altitudes. Furthermore, there is less aerodynamic drag at higher altitudes.

Yeager soon approached Mach 0.85, the speed beyond which there existed no wind tunnel data on the problems of transonic flight in 1947. The X-1 began experiencing buffeting at a speed of Mach 0.90, as the local airflow over the top of the wing became supersonic. This supersonic pocket was terminated on the downstream end by a shockwave, oriented almost perpendicular to the flow.

During previous flights, Yeager had tried different procedures to accelerate beyond this point but had been unsuccessful. He was undaunted, however, by the buffeting vibration and instability of the aircraft.

Yeager continued pushing the throttle forward. He watched the needle edge ever-so-slightly past Mach 1.0 for the first time.

A sonic boom echoed over the desert as the X-1 reached the speed of sound.

The X-1's buffeting subsided as the aircraft reached supersonic speed.

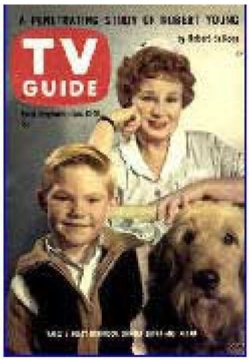
Yeager reached a velocity of 700 miles per hour, Mach 1.06, at 43,000 feet. Afterward, he made a safe landing on the dry lake bed.

An account of Yeager's supersonic flight was leaked by the trade journal *Aviation Week* in December 1947. The U.S. government kept it officially secret until June 15, 1948, however.

The knowledge gained by Yeager's historical flight allowed engineers to design planes to more smoothly and safely break the sound barrier. It also enabled pilots to understand the dynamics of supersonic flight.

Vibration in Classic TV Sitcoms By Tom Irvine

Hazel



Cast

Shirley Booth	Hazel Burke
Whitney Blake	Dorothy Baxter
Bobby Buntrock	Harold Baxter
Don DeFore	George Baxter

Hazel was the Baxter family's maid. George Baxter was the head of the family which consisted of his wife, Dorothy and their son, Harold. With resourcefulness and whirlwind energy, Hazel kept the Baxter family running smoothly. Hazel often outwitted her employer George when challenges arose. By the end of these episodes, George, with a reluctant smile, would congratulate Hazel for her determined problem solving skills.

An episode titled "A Matter of Principle" was aired on October 19, 1961.

In this episode, Hazel and George's young son Harold drive to the market to buy some meat for an important dinner for George and his client. The parking space has a meter. The meter has some time remaining, but Hazel and Harold insert some coins into the meter so that they will have extra time. As they return from shopping, however, the meter has expired and the car has a ticket.

The parking fine is only $2.00. George offers to pay the ticket. Hazel, however, insists that she is innocent. Furthermore, she demands that George, who is an attorney, defend her in court. George reluctantly agrees.

During the trial, George realizes that a construction crew was operating a jack-hammer nearby the parking meter when the alleged violation occurred. George then arranges for the court proceedings to be moved outside to meter in question. George then inserts some coins into the meter and has the construction crew restart the jack-hammer. The ground-borne vibration from the jack-hammer quickly causes the meter to malfunction by triggering the expired flag. George wins Hazel's case. As a bonus, George's client is present and observes the victory.

Congratulations to the show's writers for using construction vibration as a plot element and in a plausible manner.

I Love Lucy

Cast	
Lucille Ball	Lucy Ricardo
Desi Arnaz	Ricky Ricardo
Vivian Vance	Ethel Mertz
William Frawley	Fred Mertz

The episode of I Love Lucy entitled "First Stop" aired on January 17, 1955.

After a long day of non-stop driving, the Ricardos and the Mertzes pull into a run-down cafe somewhere on the way to Cincinnati. The cafe only serves stale cheese sandwiches. After they decide to drive on, they are tricked by misleading signs along the road, and end up back at the cafe, which also has one hotel room.

The four travelers are so tired that they reluctantly agree to rent the room, which like the café is in disrepair. Fred and Ethel take the bunk beds, while Ricky and Lucy take the double bed.

As they settle down, they are awakened by the sound and vibration of a train, which must be running along tracks right outside their room. The whole room shakes violently in response. Lucy and Ricky's bed jerks along the floor, running into Fred and Ethel's bunk beds. A moment later another train passes by going the opposite direction. As a result, Lucy and Ricky's bed skips back to its original location.

The four become so disgusted that they decide to leave the hotel in the middle of the night.

This scene is considered by some as a "blooper," because there is a wire visible on the floor that was used for moving the bed.

That railway vibration could actually cause a bed to hop along the floor is an obvious stretch of the imagination. The scene is nevertheless hysterical. The image above is of a refrigerator magnet which commemorates the episode.

Leave It to Beaver

Cast

Barbara Billingsley	June Cleaver
Hugh Beaumont	Ward Cleaver
Jerry Mathers	Beaver (Theodore) Cleaver
Tony Dow	Wally Cleaver

"Leave it to Beaver" was a television series which gave an idealistic portrayal of family life in America in the 1950s.

The episode "Beaver Takes a Bath" was aired on October 10, 1959. The parents, Ward and June, are going out for the evening. Ward leaves Wally, the older son, in charge. Wally cooks hamburgers for his and Beaver's dinner. While the hamburgers are cooking, Wally sends Beaver upstairs to take a bath.

Later, Wally calls Beaver to come down for dinner, but Beaver forgets to turn the water off before he leaves the bathroom. As a result, the tub overflows. A portion kitchen ceiling becomes soaked with water as a result. The boys then use a hair dyer to dry the kitchen ceiling.

There is no evidence of the incident when the parents return. Sometime later, however, chunks of plaster pop out from the kitchen ceiling and onto the floor. The father, Ward Cleaver, explains that vibration from a passing truck or aircraft may have caused the plaster pieces to dislodge.

The two Cleaver boys realize that the ceiling plaster failure was due to water damage, however. Their first thought is to remain silent on the issue. They soon make a confession, as matter of conscience. Ward, the firm but loving father, accepts their apology.

Ward's initial assessment that the plaster failure was due to vibration is plausible. Even though water damage was the main cause of the failure, vibration could have triggered the actual collapse of the plaster chunks.

As an aside, Ward is portrayed as having served as a construction engineer in the U.S. Navy SeaBee unit during World War II.

Note that the threshold for plaster cracking occurs at vibration velocities of 2.5 to 12 mm/sec (0.1 to 0.5 in/sec), although these numbers were not presented in the TV episode.