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On the History and Semantics of Burble in Aerodynamic Theory

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The term burble has been in use in aerodynamic theory for over a century. While burble may be unfamiliar to most contemporary aerodynamicists, the word has a rich history based in aerodynamic theory and experimentation. The present paper outlines the fluidity of burble's meaning over time. From analyzing subsonic flow over an airfoil, to the implementation of stochastic turbulence in aircraft carrier landing simulations, the term burble has had a significant impact on the study of aerodynamics. The term burble has fallen out of use in aerodynamic engineering circles. Why did this happen? And what can be learned from the decline in use of the term burble?

I. Introduction

What is burble? And what does burble have to do with aerodynamic theory? A century ago, these would have been easy to answer questions, but not today. The word burble has all but disappeared from aerodynamics jargon. The present paper does not seek to redress this disappearance but merely to address the history and effect of the term burble.

Words and their meanings have a powerful effect on communication. Words can develop in meaning over time, as well as fall out of use. While we as communicators are not typically concerned with how a word came into being, we do concern ourselves with the exact meaning and connotation of words. There is more attached to the meaning of a word such as burble than the strict definition. In the present paper the connotations that are connected to burble will be included in this meaning. The connotations of words further implicate a specific connection or scenario. This level of specificity can create layers of nuance in science and engineering vocabulary.

The origin of a word has a significant impact on its usage and development. For example, though the present paper addresses the use of burble in aerodynamic history, burble was used much earlier (upon which usage the first application of the term burble relied). The meaning of a word also develops over time, giving fluidity to the definition or the connotation of the word. One need only consider how the words and phrases 'mask', 'mask up', 'social distance', and 'pandemic' have morphed in meaning and connotation since the COVID-19 pandemic. In a similar vein, how have words such as 'browsing', 'privacy', and even 'window' and 'mouse' changed with the advent of computers and the internet? This fluidity can result in both minute and macroscopic morphing of word definition and use.

What can be learned from how the term burble progressed and developed? A word can change over time, not only in meaning, but also in frequency of use for that meaning. Today the mathematical term 'derivative' is commonly used for what Sir Isaac Newton originally called the 'fluxion' (from Latin, meaning rate of flow) [1, 2]. Old aerodynamicists used the term 'resistance' for what today is commonly called 'drag' [3], and 'angle of incidence' for 'angle of attack' [4]. The purpose of the present paper is to study the word 'burble': its meaning, origin, history, decline, and influence. The present paper is a study of the contextual use of the word burble throughout the published body of work in aerodynamics. The authors note that with some few exceptions, every publication cited in the present paper contains a variation of the word burble (burble, burbled, burbling, etc.) in the publication's body of text. Similarly, all figures replicated in the present paper were chosen either due to their containing the word burble or the word burble being used in the cited work in reference to the replicated figure.

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II. The Significance of Burbling

On a fundamental level, *burble* means boundary layer flow separation, pictured in Fig. 1.

Fig. 1 Burble behind an airfoil; from [5].

While the present paper will predominantly treat burble in air over a lifting surface, the term burble has been used to indicate various kinds of turbulent flow in liquids and gases. These include turbulent magma flow [6], turbulent gas [7], water flow behind a stationary propeller (shown in Fig. 2) [8], cavitation in dairy products [9], turbulent wake inside a diffuser for use with wind turbines [10], flow inside a water-pump turbine [11], flow inside and outside of a water-jet propulsion nozzle design [12] (shown in Fig. 3), mast-sail orientation methods [13], etc.

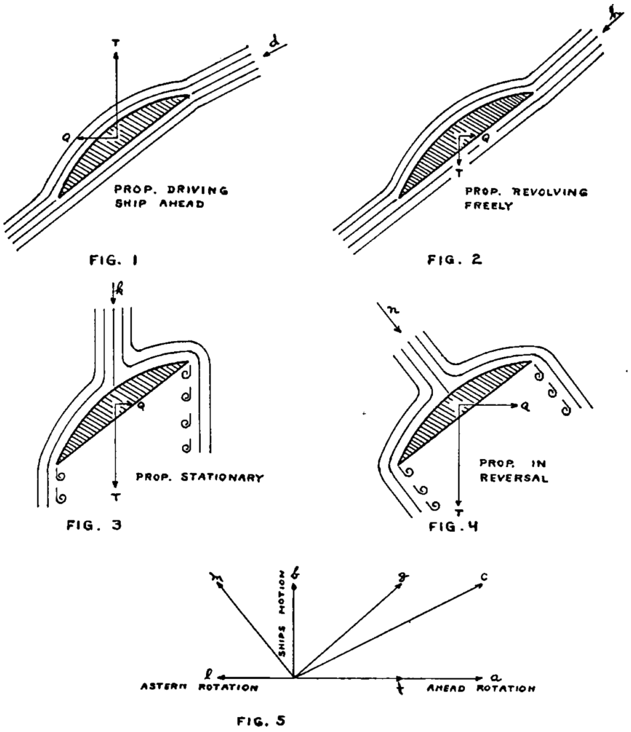


Fig. 2 Burble on ship propeller, reproduced with permission from the American Society of Naval Engineers, from Robinson [8].

The term burble dates much further back than the early 1900's and the first studies of aerodynamics. Burble has its origins in middle English, stemming from the verb "to bubble", and has been used to describe bubbling air or bubbling flow since the 1300's [14]. The word burble has also been defined as a verb meaning to confuse [15, 16], and as a noun meaning disorder [17]. Notably, since its inception burble has been used to imply perplexity and confundity. This root origin in confusion will be discussed later in the present paper.

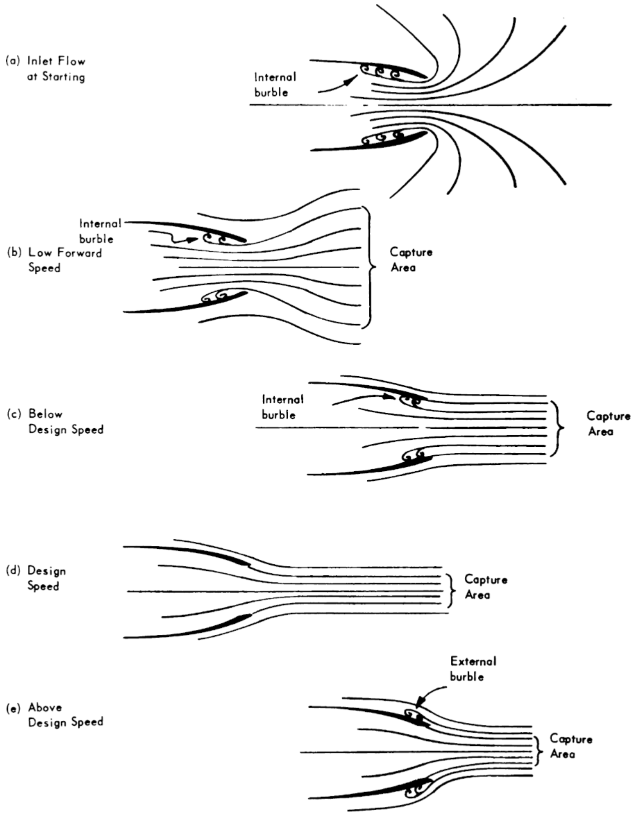


Fig. 3 Burble on water-jet propulsion nozzle at various ambient conditions, from Gongwer [12].

In aerodynamics, *burble* was first used to indicate flow which separates from a lifting surface [3, 4, 15, 16, 18–30]. At this point the burbling flow forms a turbulent wake behind the surface and streamlines are no longer smooth [31, 32]. Burble can occur regardless of fluid medium or flight regime. One of the most concise definitions for burble was given by Taylor [4]:

> The burble point occurs at that angle of incidence where the vortices in the wake of the airfoil have approached the trailing edge of the airfoil and are about to start rolling on the upper surface of the airfoil, or at that angle of attack where streamlined flow over the top of the airfoil ceases.

In modern aerodynamic terminology, the terms burble or burbling flow have largely been superseded by the term flow separation. Flow separation has been studied extensively in aerodynamics due to the profound effect it has on the flight envelopes and handling characteristics of aircraft. Variations in the lift distribution cause the aircraft to handle differently than expected by a pilot or control system. These differences can have catastrophic effects. Thus, the study of burble has been crucial to the study of flight and has seen significant developments over time due to continued theoretical improvements in fluid mechanics and flight dynamics.

III. History of Usage

The term burble has been used since aerodynamicists first studied airflow over lifting surfaces. To a small degree, the term is still in use today. In aerodynamics, burble has been used in six semi-distinct contexts. Though those six uses have not been perfectly delineated across periods of time, their use has generally followed the order in which the phrases are given in the present paper. The following pieces of history elucidate how the term burble has been employed and morphed over the years.

A. The Burble Point

One of the first usages of the term burble in aerodynamics occurs in the Great Britain Advisory Committee on Aeronautics report for the years 1912 to 1913 [33]. The report states:

> The added trouble due to the critical angle of the wing, which has been appropriately called the "burble" point, from the fact of the change of the air flow from regular to eddying. Again, if the fin arrangement is such that the aeroplane is liable to large yawing moments, whether positive or negative, the machine is exposed to being thrown off her course by side gusts.

This 1914 reference may be the earliest digitized use of the term burble in aerodynamic theory. The report describes eddying flow as being the inspiration for the term burble. Recall the root of the term burble is disruption or confusion. This eddying qualifies the description of the flow separation characteristics. First called the *burble point*, the stalling angle of attack was historically called the burble angle, burble transition point, or the burble point [3, 15, 16, 18–24, 27, 34–56]. Burble was an important term in the fledgling study of aerodynamics, defined in dictionaries [31, 55, 57–59] and even included in a list of aerodynamic-related terms in a multilingual dictionary [60].

Burble was first evaluated through experimentation when measuring the forces and moments on aircraft in wind tunnel and water channel tests. Hunsaker presented lift curves for various biplane configurations, noting the effects on burble characteristics of stagger (forward displacement between parallel wings) and decalage (mounting angle difference between upper and lower wings) [3]. The lift curves for some configurations are shown in Fig. 4. Hunsaker noted a "double burble point" (a lift curve that has two maxima, a phenomenon noted by other groups [47]) on curve 3A, a biplane configuration where the top wing has a higher mounting angle than the bottom wing.

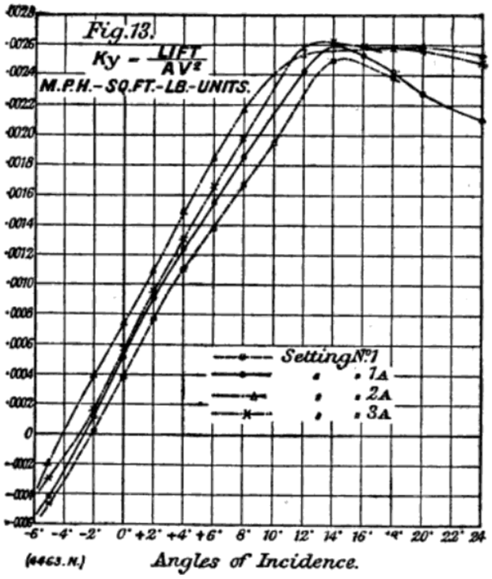


Fig. 4 Biplane lift curves, from Hunsaker [3].

Hunsaker noted a smooth transition to this burble point to be preferable for new pilots, recommending such characteristics for trainer aircraft. Hunsaker was not the only one to study the effect of various aircraft design parameters on burble. Fairbanks studied the effect of sesquiplane configuration on burble [61]. Fairbanks found the lower wing of a sesquiplane to have no effect on the burble point of the upper wing, but the lower wing had a higher burble point when joined to the upper wing. A drawing of the effect of burble on the spanwise pressure distribution of both the upper and lower wings is shown in Fig. 5.

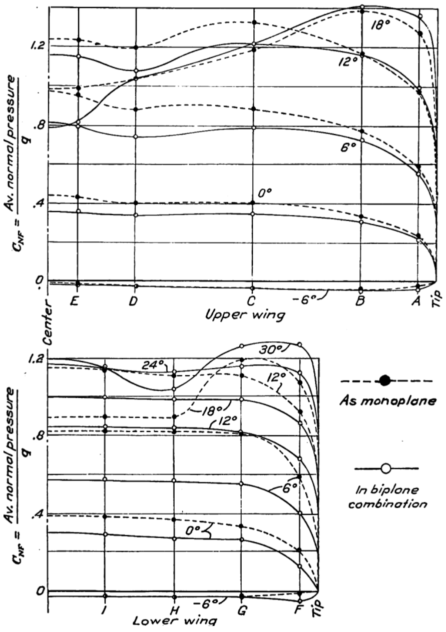


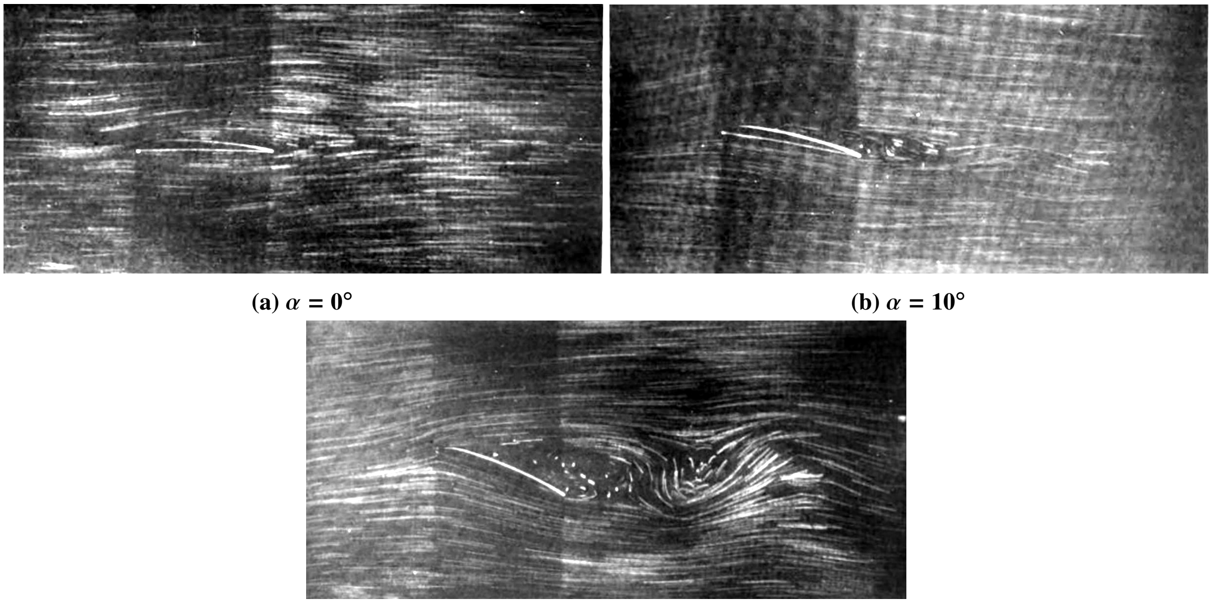
Fig. 5 Effect of burble on spanwise pressure distribution, from Fairbanks [61].

In a comprehensive study, Noyes examined the effect of decalage, stagger, gap (biplane wings vertical offset, nondimensionalized by wing chord), sweep, and overhang (percent span increase in lower wing) [62]. Noyes found gaps greater than unity to increase maximum normal force, and smaller gaps to delay burble to higher angles of attack. The study also reported positive stagger (upper wing forward) to increase the maximum normal force, and that stagger could be used to separate the upper and lower wing burble points (to prevent catastrophic stall). Noyes found some parameters to have equal and opposite effects on shifting the burble point, such as negative stagger and positive sweep. Noyes also found any overhang to be less desirable than none as far as burbling characteristics are concerned.

Other research groups studied similar parametric analyses on lighter-than-air craft. Smith and Whipple noted airships burble at a critical bluntness where the spindle form (streamlined airship geometry, like a teardrop shape) had a fineness ratio less than two [63]. Upson and Klikoff found similar properties for airships, noting the fineness ratio for minimum drag to be greater than that which induces burble [64]. Upson and Klikoff noted three forms of drag for airships: viscous hull drag, burbling hull drag, and parasitic drag, and theorized the burbling hull drag to decrease to zero with increasing fineness ratio.

These first uses of the word burble demonstrate how a word is treated when introduced in the aerodynamicist's jargon. Several texts surround burble and burble point with quotation marks. This could be to emphasize an unfamiliar term as well as highlight an interim word for future renaming. This can especially be seen in the work of Page [57]. Page uses quotation marks around terms which were then unfamiliar to the aerodynamic community. These terms include 'burble point', 'lift curve', 'drift' (for drag), 'top camber' and 'bottom camber' (for upper and lower surfaces of an airfoil), 'head resistance' and 'parasitic resistance' (for fuselage drag), 'wing resistance' (for wing drag), and aircraft 'gross weight'.

The burble phenomenon was also presented via flow visualization in these wind tunnel and water channel tests. What could be learned from these visualizations? Photographs presented by Cowley and Levy of burbling flow behind an airfoil, a circular cylinder, and a flat plate are shown in Figs. 6, and 7 [21].

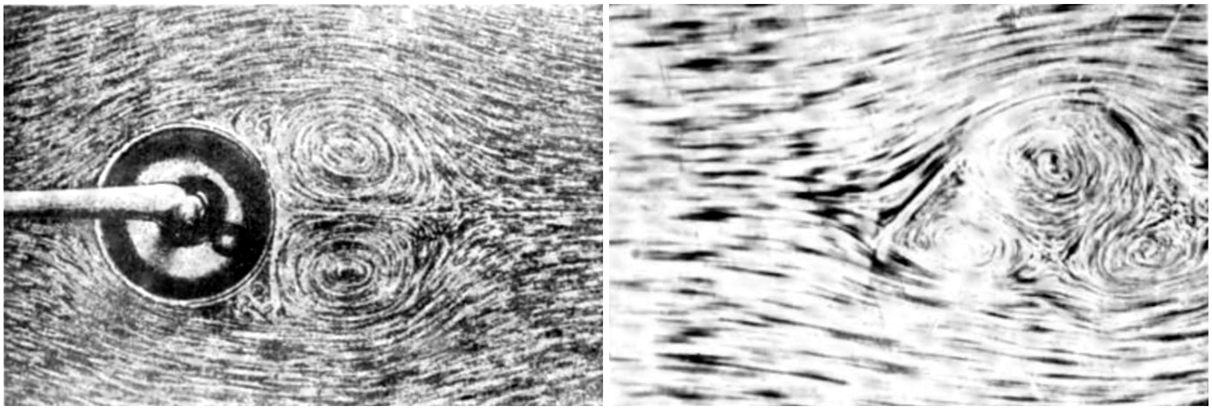


(a) α **= 0°**

(b) α **= 10°**

(c) α **= 20°**

Fig. 6 Burble over an airfoil at various angles of attack α**, from Cowley and Levy [21].**



(a) Circular cylinder

(b) Flat plate

Fig. 7 Burble flow behind other geometries, from Cowley and Levy [21].

Regarding the transition to burbling flow Cowley and Levy noted [21]:

> The real cause of this rapid transition will not naturally be clearly understood until considerably more progress has been made in the theory of fluid motion, but the fact of its occurrence is of vital consequence for a thoroughly reliable anticipation of the performance of an aerofoil. The effect of this so-called "burble" point not unnaturally becomes apparent when the measurement of the forces brought into play on an aerofoil are undertaken in the wind channel. At the burble point the lifting forces drop sharply and just as quickly rise again.

Three key points can be gleaned from this statement. First, the cause of boundary layer separating from the surface was not well understood. Second, attention should be given to Cowley and Levy's use of quotation marks around and "so-called" description of burble. Lastly, the detrimental effect of stall on the wing lift-force was emphasized ("vital consequence"). These points together show that aerodynamic theory had not developed sufficiently to explain the origins of burble, or which term to indicate this flow separation, but aerodynamicists knew what burble affected: lift! The effect of the burble point on the pressure distribution was also noted to influence drag [65] and pitching moment [37]. This understanding would form the basis of future studies of aircraft stall characteristics.

Not all aerodynamicists were as concerned as Cowley and Levy. Warner and Norton noted [22]:

> It is, therefore, evident that the burble point is of very little practical interest in airplane design, as it is improbable that any pilot ever flies his machine at that angle voluntarily except for a very brief interval in the course of a stunt or when testing for minimum speed.

However, this appears to be a less popular opinion. Recall burble was first encountered via experimentation. Various groups noted with concern predominant aerodynamic theories such as Munk's thin airfoil theory [66] and Prandtl's lifting line theory [67] were unable to predict the burble point. This left experimentation as the only method for studying the burble point. However, wind tunnel results were difficult to analyze in the burble region due to pressure distribution on the airfoil surface being unsteady past the burble point [39, 68–73]. However, these results did show the burble point to generally occur at high angles of attack [63, 69–72, 74], a finding expressed by Gillmer and Nietsch in Figs. 8 and 9. Similar studies showed burble to be affected by Reynolds number [39, 75, 76], finding lifting surfaces at high angles of attack to more readily burble at slow speeds.

Fig. 8 Burble in wing flight phases, from Gillmer and Nietsch [51].

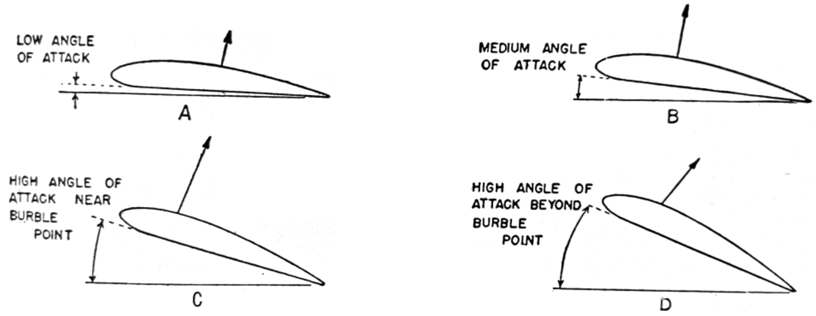


Fig. 9 Angle of attack effect on center of pressure, lift, and burble, from Gillmer and Nietsch [51].

Though aerodynamicists did not fully understand burble, they did understand burble could be more simply analyzed on two-dimensional airfoils. Knight and Bamber noted the shape of the lift curve maxima to be dependent on how the burble occurred over the upper surface of the airfoil [77]. Jacobs, Stack, and Pinkerton noted increasing Reynolds number delayed the burble, with greater effect on symmetric airfoils than asymmetric airfoils [75]. Others found thicker airfoils to have larger minimum drag and higher maximum lift [78]. Several groups studied airfoils below the burble point because it was difficult to quantify the effect of burble [79].

This airfoil research was crucial to the groups studying propeller burble. Pilots noticed frequent flow separation off the propeller in certain flight conditions. One of the first studies of burble effects on propellers was on helicopter rotors [35]. It was noted by Caldwell that changes in airfoil design could delay the burble produced by propeller tips, quantifying a relationship between airfoil camber, propeller pitch, and propeller tip speed [80]. Jacobs noted burble to affect propeller lift slope where the propeller airfoil had a larger maximum thickness [81], shown in Fig. 10.

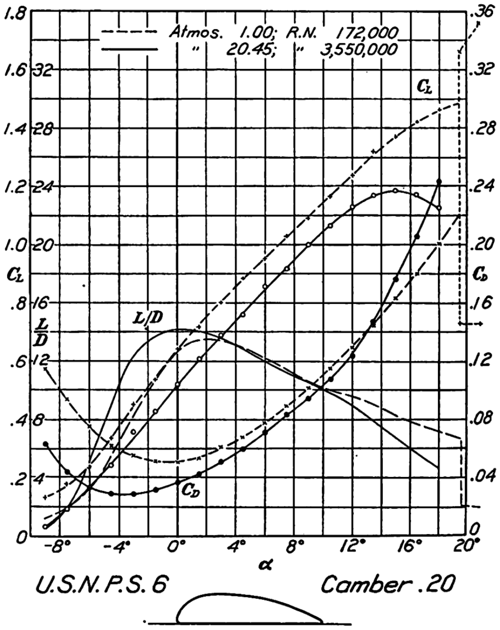


Fig. 10 Effect of burble caused by airfoil thickness on lift curve, from Jacobs [81].

In the late 1920's and early 1930's the term burble point began to leave aerodynamics vocabulary. With increasing theoretical understanding of burbling flow and field developments, aerodynamicists began to use the term *flow separation* to describe burble [77, 82, 83]. Some groups began to define the eddying flow behind an airfoil as "flow separation or burble" [77, 83]. The phrase flow separation began to replace the burble.

Coinciding with the term shift from burble to flow separation, some groups theorized on the original application of the term burble to aerodynamics. In a 1929 review of the mathematical problems yet to be solved in aerodynamics Levy noted a critical angle of attack where the aft flow switches to turbulent and eddying, the "so-called . . . 'burble point'" [84, 85]. After defining the burble point, Levy said "to use a technical term that has been borrowed from the Jabberwock". This reference pertains to the poem *The Jabberwock* published in Lewis Carroll's *Through the Looking-Glass* reproduced in part here [86]:

The Jabberwock, with eyes of flame,
Came whiffling through the tulgey wood,
And burbled as it came!

The reference in Levy's work is not alone. In the commentary on Jones' 1937 article *Profile Drag*, it was noted [87] (reproduced with permission):

> It seemed that Lewis Carroll was responsible for one of the words used in aeronautics. It was quite obvious that the Jabberwock could fly stalled, for it was definitely stated that it "burbled as it came." Mr. Relf believed that that was the origin of the application of the word "burble" to stalling!

Similarly, in Rosenhead's review of Milne's *Theoretical Hydrodynamics* [88] he noted the work to cite Lewis Carroll's *Through the Looking-Glass* for the word burble [89]. Whether or not the term burble originated from the work of Carroll it is interesting to note that within eleven years of the introduction of the word burble aerodynamicists were still unsure from where the word had originated.

B. Interference Burble

With increasing comprehension of the causes for burble, various aerodynamicists developed methods to mitigate or design around burble. Some groups studied burble over aircraft control-surfaces [34, 90]. Jacobs and Pinkerton evaluated the flow burble behind wing flaps [90], shown in Fig. 11.

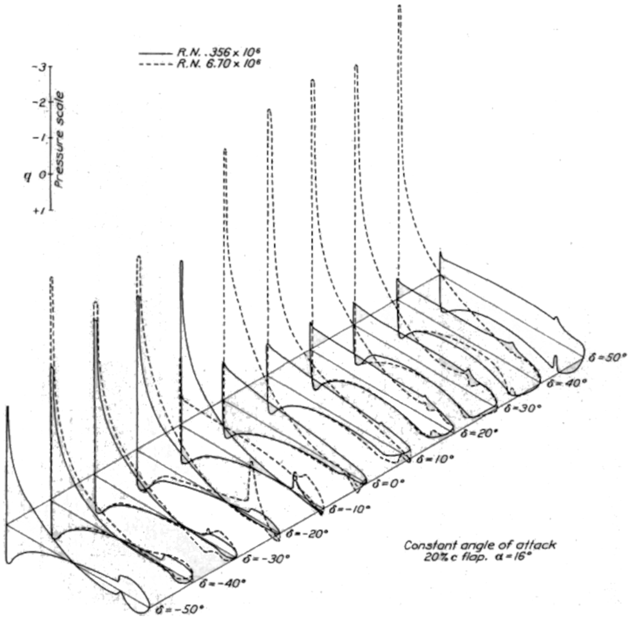


Fig. 11 Wing burble caused by flap deflection, from Jacobs and Pinkerton [90].

Jacobs and Pinkerton found burble was delayed with increasing Reynolds number. With improved aircraft design and engine performance, ability and necessity led to increased research on flow separation. This research was particularly focused on which flow conditions produced burble. Smith noted burbling to occur in regions with low Reynolds number and low lift coefficient, and regions with high Reynolds number and high lift coefficient [91]. Smith's drawing of the spanwise burble line on a wing is shown in Fig. 12. Rhode found the burble (or stall) speed to also be a function of load factor and altitude [28].

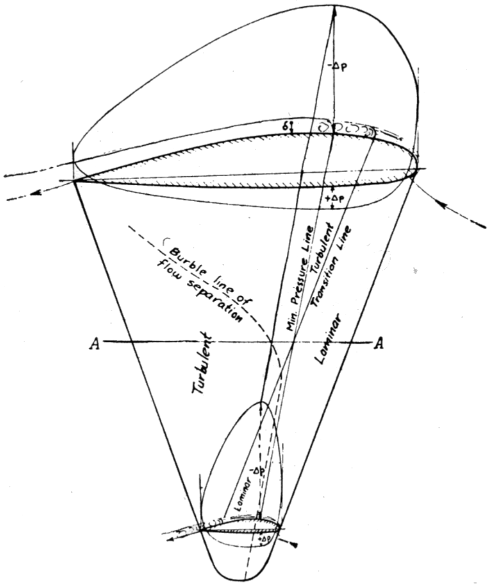


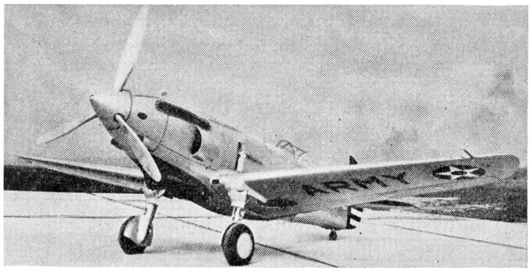
Fig. 12 Burble separation line on a wing, from Smith [91]; reprinted by permission of the American Institute of Aeronautics and Astronautics, Inc.

One method used to determine the shape and location of burble was through the "wool tuft method", where strings are attached to the surface of a wing. In burbling flow, eddies cause the strings to move erratically. As one of the first users of this method, Jones noted this method to show where interference (flow separation from one geometry affecting another) occurred on the wing [87]. This and other testing methods showed that burble does not occur symmetrically along wings [72, 92], and this asymmetry in burble was partly to blame for flat spin stall [93]. Other groups found burble to have a significant effect on yawing and rolling moments [72, 94, 95], finding the change in yawing moment with respect to lift coefficient to be greater than the change in rolling moment with respect to lift coefficient above burble [95].

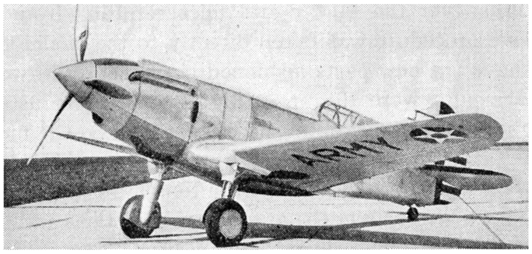
The asymmetry and buffeting of burble were analyzed on various aircraft components. Some groups studied the fluttering effect of burble on control surfaces [72, 92]. Others studied the effect of burbling flow on engine compressor blade tips [11] and behind engine nacelles [96, 97], finding this disturbed flow to cause instability in the aircraft dynamics [97]. White and Hood analyzed the burbling angle for the *McDonnell* airplane with variations in wing and propulsion geometry: fillets, engine cowlings, and reflexed trailing edges [98]. Zimmerman found wings with semicircular wing tips to have a higher maximum lift coefficient than wings with rectangular or faired wing tips [99]. Libbey studied the effect of aspect ratio of lower aft vertical stabilizers on burbling characteristics [100]. Sherman examined the effect of wing cut-outs on burbling characteristics [101], an example of which is shown in Fig. 13. Each of these groups studied how different aircraft design changes influence the burble characteristics of the aircraft.

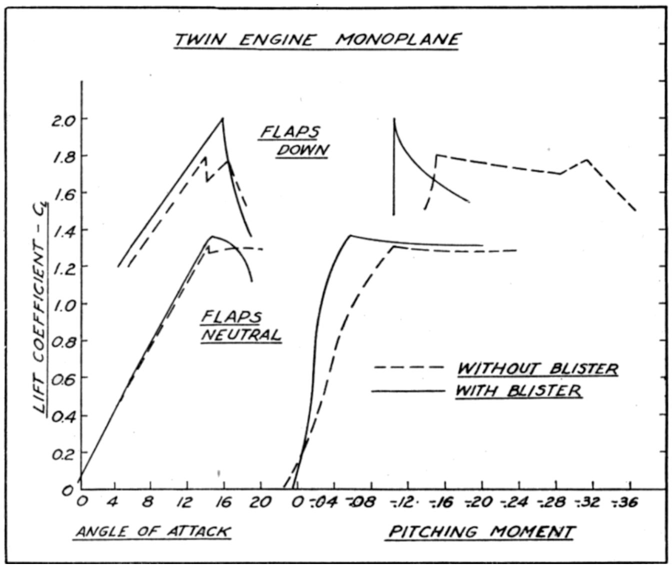
Fig. 13 Wing cutout noted for earlier burble onset, from Sherman [101].

With a deeper understanding of how these design changes affected the burble, aerodynamicists also studied changing design to avoid burble. Some groups studied the burble flow separation caused by joined aircraft surfaces, such as the wings and fuselage [29, 102]. This flow was termed *interference burble* [26, 102]. Hovgard noted a marked improvement in burble onset characteristics when adding a blister to the wing root, which was attributed in part to the increase in wing root chord and camber [102]. The blister and corresponding effects on the lift and pitching moment are shown in Fig. 14.



(a) Without blister





(b) With blister

(c) lift curves

Fig. 14 Blister on the Curtis Allison Pursuit causes reduced interference burble, from Hovgard [102]; reprinted by permission of the American Institute of Aeronautics and Astronautics, Inc.

Aerodynamicists had found the effects of the interference burble could be mitigated in all components of aircraft design. Knack noted the angle between the fuselage and the ground must be below the burble point angle [103]. Klein studied the use of fillets between the fuselage and wings to remove 'pockets', which decrease burble at high angles of attack [104]. These pockets were particularly common in aircraft designs at the time due to wings being joined to the bottom of the fuselage. An example fuselage to wing fillet is shown in Fig. 15. Due to the success of these groups in mitigating burble other groups recognized the burble to be a manageable phenomenon and studied theoretical aircraft unaffected by burble. Indeed Oswald, in developing his airplane efficiency factor, proposed an ideal airplane "in connection with which the phenomenon of burbling does not occur." [105].

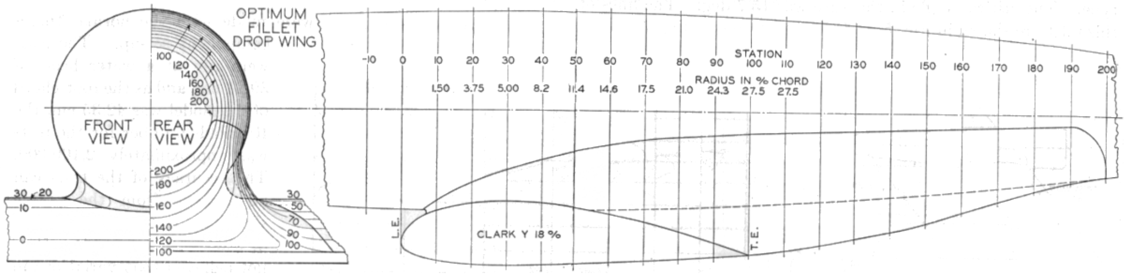
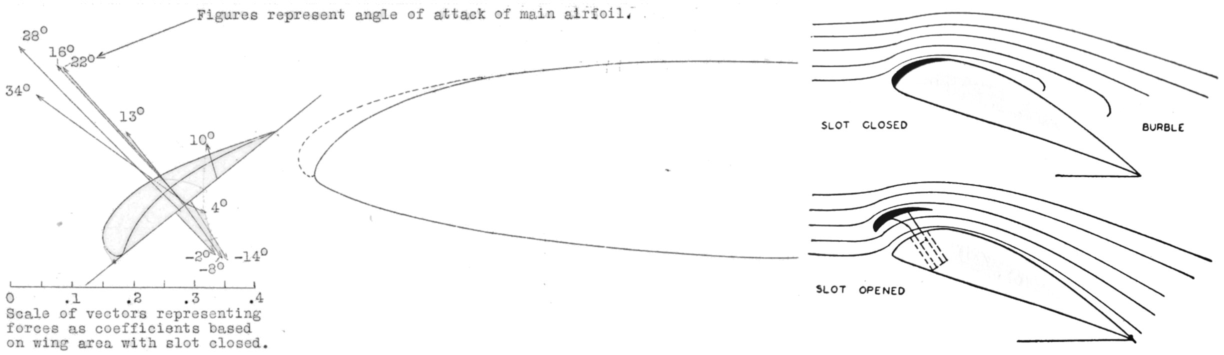


Fig. 15 Wing-fuselage optimum fillet for minimizing interference burble, from Klein [104]; reprinted by permission of the American Society of Mechanical Engineers.

Perhaps the most inventive change in design to avoid the effects of burble was that presented by Clay. Clay studied the use of a small wing positioned in front of the aircraft windshield to deflect rain away from a small opening in the windshield [106]. Clay noted the burbling of the deflector wing could be avoided by simply inverting the wing. Another design change method involved the use of leading edge slats which could be extended into the flow to keep the flow attached to the upper wing surface longer [32, 56, 93, 107, 108], potentially doubling the burble angle [108, 109] and improving lateral control at slow speeds [93, 109]. Drawings of such wing slots are shown from two different works in Fig. 16.



(a) Slat design, From Jacobs [107] **(b) Slat effect, from Lusk [93].**

Fig. 16 Airfoil leading-edge slats for improved lift after burble.

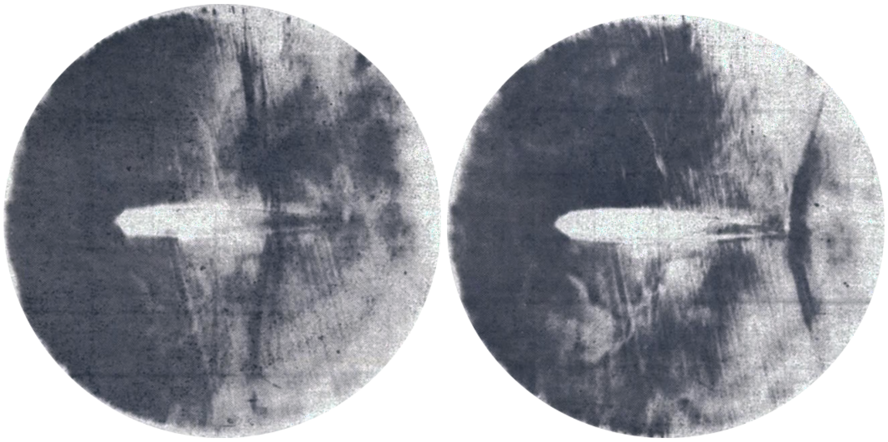
While aerodynamicists had found methods to avoid and mitigate interference burble, they also developed methods to utilize burbling flow. Spoiler designs were used to produce separated flow with the intended consequence of decreasing lift and increasing drag [109, 110]. Weick and Shortal noted spoilers which ended at 80% span to cause burbling 20% further along the wing [110]. One particular method was noted by Lanchester: He theorized the flow over a wing surface could be tripped to postpone burble and produce a higher maximum lift coefficient [111]. These subsonic studies of burble prepared aerodynamicists for expanded flight regimes.

C. The Compressibility Burble

With improved wind-tunnel designs and faster aircraft, compressible flow became the primary developing area of burble study. In preliminary experiments aerodynamicists found bodies in supersonic flow developed shock waves. Turbulent flow would arise as a result of these shock waves. This shock-induced turbulent flow was called the *compressibility burble* [54, 55, 112–138], a term coined by Stack in 1933. In Stack's later report titled *The Compressibility Burble* he stated [115]:

> The source of the increased drag observed at the compressibility burble is the compression shock and the excess drag is due to the conversion of a considerable amount of the air-stream kinetic energy into heat at the compression shock.

Within this report Stack presented Schlieren photographs for a wing encountering the compressibility burble, replicated in Fig. 17.



(a) $M \leq 0.79$ **(b) $M > 0.79$**

Fig. 17 Schlieren photographs of a wing in subsonic and transonic flow, from Stack [115].

Initially, aerodynamicists had only studied the compressibility burble on propellers [128, 131, 139]. Various groups found increased angle of attack [112], increased thickness [140, 141], increased camber [142, 143], and increased leading edge radius [140, 142] to all decrease the speed at which a given airfoil encounters the compressibility burble. The effect of the compressibility burble on lift and drag coefficients is shown in Fig. 18.

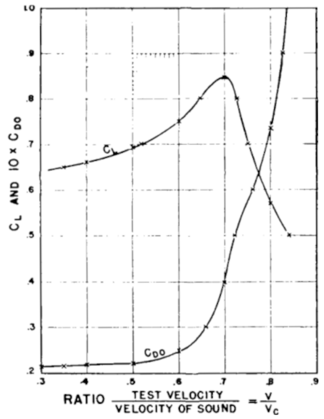


Fig. 18 Compressibility burble occurring on a NACA 2409-34 airfoil at $M = 0.7$, from Diehl [141].

Stack and Von Doenhoff studied the particular effect of maximum thickness on compressibility burble onset. Stack and Von Doenhoff stated "Airfoils having the position of maximum thickness forward or aft of the 40 percent location have progressively higher minimum profile drags and earlier compressibility burble." [140]. Two particular results of this work were the discovery that the compressibility burble significantly affected airfoil aerodynamics. First, after the compressibility burble speed (known as critical Mach) is reached, the zero-lift angle of attack of a cambered airfoil approaches zero. Second, past the compressibility burble speed lift drops off, the center of pressure rapidly moves aft, and the pitching moment becomes largely negative. Stack and Von Doenhoff noted this particular phenomenon (known as Mach tuck) should be studied for the case of dive-bombing aircraft. This concern proved prophetic. The development of the Lockheed P-38 Lightning was a particular example in aerodynamic history of aircraft experiencing the compressibility burble in a dive [144].

With continued research on the causes and concerns with compressibility burble, aerodynamicists incorporated lessons learned from burble in related areas. Perhaps the most striking example was the use of subsonic airfoils as hydrofoils. Chadwick noted [138]:

> It happens that the prediction of the cavitation limit for hydrofoils is very closely analogous to the prediction of the compressibility burble point (critical Mach number) for airfoils. Because of the monotonic one-one correspondence between velocity and pressure, anti-burble sections must have the same characteristics as anti-cavitation sections, i.e. tend to produce uniform pressure distribution.

Indeed, Chadwick cited prior use of a subsonic airfoil as a hydrofoil. Note the use of the term burble in conjunction with cavitation, as in the study of dairy cavitation in [9].

However, Stack noted the development of new flight regimes as the impetus for moving the study of the compressibility burble from being a "propeller problem" (or for that matter an "airfoil problem") to being a "wing problem" [131]. Indeed, regarding the compressibility burble these new flight regimes introduced a "whole-airplane problem".

The study of compressibility on propellers and wings was extended to all components of the aircraft. Robinson and Becker evaluated compressibility on engine cowlings [145]. The pressure distribution over a cowling at different Mach numbers is shown in Fig. 19. Studies of the compressibility burble also extended to the nose of aircraft fuselages. Klemin published studies on supersonic flow over spheres and airfoils, noting "blunt-nosed or even rounded-nose fuselages may have to be changed radically in form when the aeroplane flies at really high speeds." [117]. Through the study of faster aircraft (and expanded flight regimes) aerodynamicists noticed potential benefits to producing uniform burble.

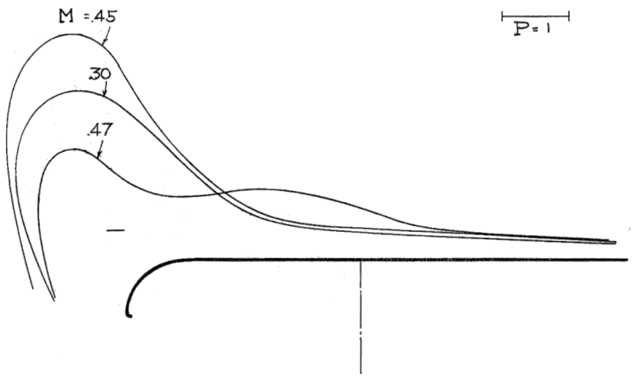


Fig. 19 Change in pressure distribution over engine cowling due to compressibility burble, from Robinson and Becker [145].

D. Burble Fences

Skydivers skillfully use flow separation to maneuver, change orientation, and modify diving speed. Burble has been used to describe the flow separation behind a skydiver [146–148]. One area of concern is when burble flow behind a skydiver prevents their parachute from opening well [146, 147]. Another concern stems from the use of diving altimeters. These altimeters are pressure sensors, typically on the skydiver's wrist, used to estimate the current altitude. When these sensors are fouled by burbling flow, the readings can be incorrect, a death knell for skydivers due to the precise timing (or knowledge of altitude) required for chute release, etc.

Aerodynamicists also found benefits to producing burble flow, with groups studying burble-inducing geometries. These geometries, called *burble fences* [149–153], are generally toroidal structures which induce uniform flow separation over a surface. Burble fences are typically incorporated to increase drag on a design and filled using ram air scoops [152]. Burble fences have been built on inflatable decelerators for use with weather balloons [154], missiles [137], aircraft [155], and spacecraft reentry vehicles [156–161]. A drawing of a burble fence designed for use with drag decelerators on the X-15 aircraft is shown in Fig. 20.

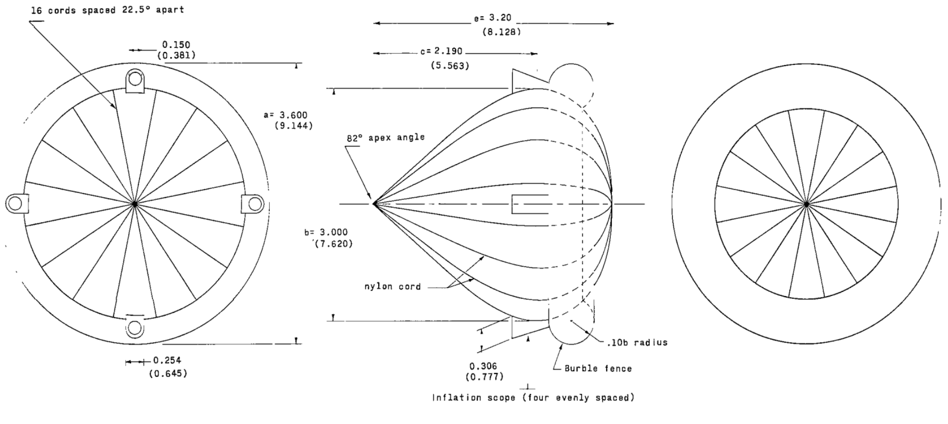


Fig. 20 Drawing of a burble fence, from Campbell [155].

The main purpose of attaching burble fences to inflatable decelerators is to produce uniform flow separation [162]. This can significantly improve aerodynamic stability in subsonic [154, 158, 162–168] and transonic flow [163] but can cause inefficiency in supersonic flow [167]. Various groups found useful improvements to conventional decelerator design. Maclanahan studied the use of an alcohol and water solution to improve time to inflation [169]. Fallon studied the use of a simple ribbon in place of a toroidal burble fence which decreased mass, bulk, and complexity while ensuring uniform flow separation [162]. One novel implementation is that developed by Smith et. al. [170]. This group studied a gun-launched unmanned aerial vehicle which would deploy an aerodynamic decelerator (with burble fence) to stabilize the vehicle after launch. This would give the aircraft time for wings to extend and propulsion systems to initiate. The term burble fence is still in use today, albeit in minimal capacity and usually surrounded in quotation marks (as it has become an unfamiliar word).

E. Burble Noise

In the 1970's and 80's there was a significant spur in research to study a phenomenon called *burble noise* [171–183]. This is a noise produced by helicopter blades caused by interaction of the main rotor tip vortices with the tail rotor [173, 178] and is sometimes called "tail rotor burble" [178]. A drawing of the burble noise wake interaction is shown in Fig. 21. Significant research effort has been expended in reducing the burble noise [172, 173, 180] because the burble noise can be quite significant for many flight scenarios [184]. This phenomenon was noted to increase pilot workload, especially in close proximity to buildings [185].

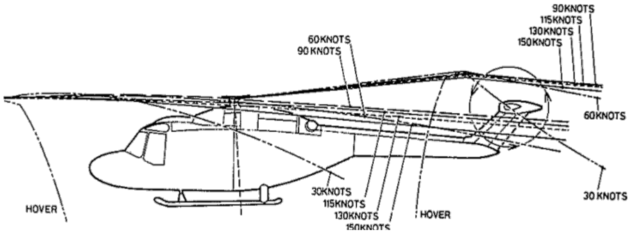


Fig. 21 Diagram of rotor wake of helicopter blades which causes the burble noise, from Leverton [172].

The term burble noise was first used by Leverton et. al. [186]. Leverton et. al. describe the noise interaction as a "a deep throated 'burbling' noise", which was particularly noticeable in flyover, but not hover. This was due to the main rotor wake interacting with the tail rotor as shown in Fig. 21. They found that rotating the tail rotor in the opposite direction (top going aft rather than top going forward) significantly reduced the burble noise. Suttie noted this solution to work because the burble noise is deflected upward rather than downward [187]. Suttie also noted the burble noise can be reduced by decreasing tail rotation rate or increasing rotor chord, radius, or tip weight. With the problem more or less mitigated, the term declined in use. The term burble noise was rarely used without quotation marks.

F. The Burble

The final contextual use of burble in aerodynamics relates to flight through flow which has separated off a non-lifting surface. The turbulent flow in the air behind an aircraft carrier has frequently been called *the Burble** [188–211], depicted in Fig. 22. Publications from the inception of the word burble used quotation marks to denote the word burble as new, and unfamiliar to the reader. With decreased use of the word burble, recent uses of the term Burble have presented the word with quotation marks, denoting Burble an old or unfamiliar word to the reader [188–190, 197, 202, 205, 208, 212]. The origin of the application of the term Burble to flow separation behind an aircraft carrier has been both been implicitly and explicitly attributed to the pilot community [202, 211, 213, 214]. The great irony of this is the term burble originally was introduced by aerodynamicists!

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*Burble is capitalized here to distinguish the specific use of burble to describe flow behind an aircraft carrier.

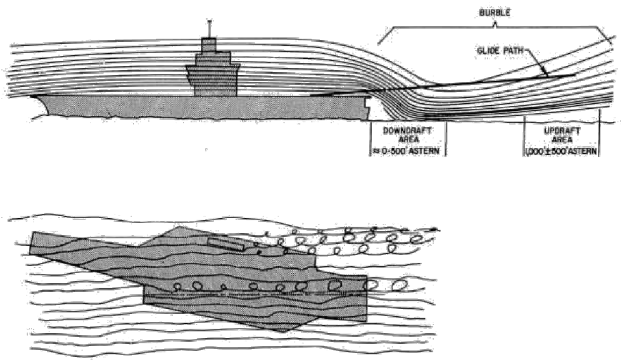

Fig. 22 Drawing of downwash and upwash in the Burble behind an aircraft carrier, from Nelson and Griffin [213].

Many groups have studied the physics of the Burble. The Burble typically results in a sharp downwash aft of the ship [206, 215], followed by upwash [206] which grows two to three ship-lengths downstream from the carrier [216] and has typically grown double in size near this point [215, 217]. Particle traces of the Burble showing this increase in size are shown in Fig. 23. Lehman noted the Burble to arise chiefly from the carrier deck, with ship roll and the carrier island having minimal effect on the Burble [190]. The Burble is periodic in nature [190, 218] with steady, periodic, and random components. The direction of the Burble depends on the freestream sideslip on the ship with respect to the wind [219].

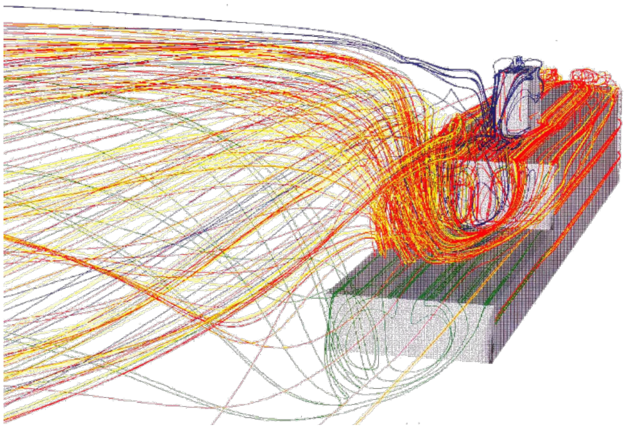

Fig. 23 Particle traces in flow over a frigate showing burble, from Tai [215].

The Burble has a detrimental effect on pilot workload and aircraft handling qualities. The Burble can increase the probability of catastrophic stall [220]. Lehman noted the Burble to affect the last 10 seconds of landing on an aircraft carrier [190]. Lehman notes the pilot typically has between one and two seconds to commit to land or abort after exiting the Burble. Though the Burble is periodic, the period of the Burble is typically longer than duration of landing. Thus, pilots typically only experience one peak of the Burble. Flying through the Burble the pilot feels a rapid decrease in lift [221] crossing the change from upwash to downwash. Jewell et. al. noted pilots tend to prepare for the Burble by changing elevator and throttle setting as they pass through [222].

Due to the powerful effect of Burble on carrier landings simulations have been developed to apply the effects of the Burble to aircraft [191, 194, 206, 218, 223, 224] and helicopters [192, 198] landing on an aircraft carrier deck. These simulations typically implement the Burble model presented in MIL-F-8785C [225], though some groups have used other models. The term Burble has disappeared from the terminology even in this more recent field of study, usually being replaced by air wake. If Burble has been introduced in recent years, it is usually given in quotation marks and called air wake thereafter [202, 205, 208, 212].

IV. Decline In Use

The history of the term burble begs the question: why did aerodynamicists stop using the term burble? The authors used the Google Ngram tool [226, 227] to map the usage of the word burble over time. The Ngram tool can be used to search digitized books for phrases of varying lengths. The usages of various burble-related phrases are plotted in Fig. 24[†]. The number reported by Google's Ngram tool for each year is the word use percentage of all words published in the year. This is done to improve the data comparison between years.

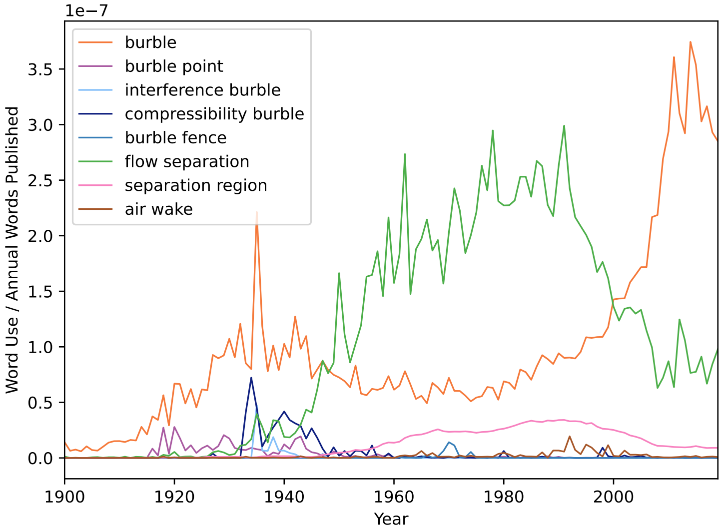

Fig. 24 Change in the use of burble phrases over time.

Figure 24 shows a spike in the use of the word burble in the mid 1930's, with the general introduction of the word occurring in the late 1910's. These trends correlate to the explosions of aerodynamics research and first studies in aerodynamics. The term burble point was typically used in the burble "early" history. The uses of compressibility burble and interference burble are near contemporaries. Also, note the use of the term burble fence predominantly in the 1970's. Burble noise and the Burble are missing from this plot. This is because burble noise was not found through the Ngrams search (due to minimal usage), and the Burble results are not reported as they can be confused with the generic usage of burble.

The term burble has been used throughout its history as a provisional descriptor. A phenomenon relating to eddying flow is studied, given a transient name relating to burble, and generally is given a condition specific name if extended study is dedicated to the topic. Thus, the term burble is a means to an end: it is not meant to stay with the meaning of the word. Two significant trends shown in Fig. 24 demonstrate this word transience: the shifting from burble to flow separation and from compressibility burble to separation region. Flow separation and separation region became the names given to the interim phrases burble and compressibility burble, specifically. The new terms have generally become more common due to the specificity of their nature.

Another reason for the declining use of the term burble is due to similarity with the word bubble. While descriptive, and lightly applicable as a term for flow separation, burble can be misconstrued as a bubbling or even vaporization of the flow. Aerodynamicists use precise words to communicate exact concepts. One can then imagine the reasoning for using the phrase flow separation over the term burble: it carries greater specific meaning. The term burble leaves room for misinterpretation.

Shown in Fig. 25 are similar phrases normalized by the word-published-percentage in 2019 (the most recent Google Ngram survey as of the writing of the present paper). The reader may have noted in Fig. 24 the continued and increasing use of the term burble, contrary to the implications in the present paper. For this reason, Fig. 25 is given for words which are similar to the version of burble not related to aerodynamics, specifically a bubbling, babbling, or gurgling noise or motion.

[†] This data is reported with no smoothing. The word counts for reported words or phrases which include burble (such as compressibility burble) are excluded from the count for the individual term burble. Counts are reported insensitive to capitalization.

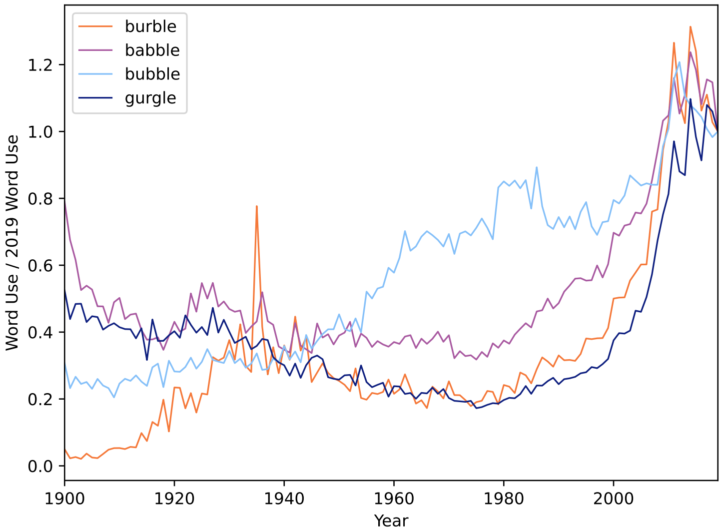

Fig. 25 Change in the normalized use of similar phrases over time.

Though bubble, babble, and gurgle have been used much more frequently than burble in past years, their trends are similar. Indeed, after the major uses of the term burble (burble point, compressibility burble), the data for the word burble follows nearly the exact trend of the terms babble and gurgle. These similar words (babble, gurgle) are used with burble because of similarities in pronunciation and meaning. Bloomfield noted the words gurgle and burble to be a particular pair that is frequently used together due to their having the same final morpheme (segments of a word) and similar meaning [228]. The rise of burble in aerodynamics in the 1930's and 40's may have caused the spread of use of the term burble in other works. However, this line of discussion lies outside the scope of the present paper.

There are over 200 reference works which use the term burble in the present paper (and 315 uses of the term in the text body), but this work is by no means exhaustive. There are over 1,000 digitized references to burble on Google Scholar[‡]. The concept of similar word usages presented in Fig. 25 can be seen in digitized Google books published between the years 1920 and 1989[§], and those published between the years 1990 and 2019[¶]. Those books published in the earlier stage are majorly (nearly eight out of every ten books) on aerodynamic experimentation and theory. Those books published in the latter stage generally address other topics (frequently fiction), with few books on aerodynamics generally (nearly one out of every ten books). Frequently the more recent uses have burble in the title of a reference such as Stack's *The Compressibility Burble* [115] (these works are not cited in the present paper). Though the word burble is not in use in aerodynamics vocabulary to the same extent as a century ago, it has left an indelible mark on the development of the field.

V. Lasting Influence and Lessons Learned

Several key lessons can be learned from the history of the word burble. While the word burble has fallen out of use, words such as flow separation and separation region have replaced it, providing clearer, more concise terms for the same meaning. In the case of the term burble this departure has occurred for various reasons.

In a study on semantics Allan notes the term used for a given meaning is usually determined via Keith prototype semantics [229]. Succinctly, Keith prototype semantics relate the term that comes to mind first for an individual when presented with a given meaning. The word that comes to mind first best fits the meaning in the mind of that person. Perhaps the term burble has perhaps fallen out of use because it no longer fits the aerodynamics meaning of the term burble; flow separation provides a better description of the effect generally.

Another form of semantics is Putnam stereotype semantics [230]. This involves the meaning of a term perhaps lying outside the "checklist" of meanings for a given word. Putnam provides examples of a TV that is broken or a

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[‡] https://tinyurl.com/scholarburblerefs
[§] https://tinyurl.com/burblepre1990
[¶] https://tinyurl.com/burblepost1990

tiger without stripes as being word applications where the "checklist" is not fully met, though the word still applies. While the word burble can be used to describe eddying flow, there are too many other "checklist" items (vaporization, bubbles, mumblings, etc.). Other words, such as babble and bubble, can be used in conjunction with the term burble. The specificity of a term can influence the use of the term. Because the term burble has such a range of applicability it has declined in use in aerodynamics due to this range of applicability.

The word burble may also have fallen out of use due to generational changes. New generational cohorts of aerodynamicists bring new ideas, and new vocabularies. This can be particularly seen in those references which surround the term burble in quotation marks. This is done to focus on the unfamiliarity of a given term for the reader, perhaps due to creation (by the author), or lack of use. Surrounding a term in quotation marks may also be done to distance the author from the term [231]. As shown in Fig. 24, the term burble has gone through phases of use. Generations of aerodynamicists study a phenomenon, and the terms they apply to this phenomenon die with them.

What has been gained by the use of the term burble? Firstly, an understanding of the burble phenomenon. A name had to be given to the phenomenon, even if it was not permanent. Communication has allowed increased knowledge of what causes, how to avoid, and how to use burble. By discontinuing use of the term burble the aerodynamics community has gained specificity. The aerodynamics community has also gained a rich history. This history, elucidated here, provides examples of giants of aerodynamics who like modern aerodynamicists were faced with research of the unknown.

What has been lost by discontinuing use of the term burble? Firstly, the decreased confusion associated with the burble. Terms such as flow separation describe in name the exact phenomenon to which they apply. The greatest loss through the discontinued use of burble is an understanding of how confused and perplexed aerodynamicists were when first encountering burble. Though the models and understanding could not initially explain the physics of burble, problem-solving and hard work rewarded these diligent researchers. This lesson from the history of burble encourages the contemporary aerodynamicist (and researchers in general) to press on: the great began with no more equipment than those who study aerodynamics in the present day.

VI. Conclusion

The meaning of a word has a powerful impact on when and where the word is used. From cultural shifts to epidemics, words are fluid in their meaning and usage. Word origin and development can also significantly alter the meaning of a given term. Change in meaning can cause words to fall out of use.

The term burble has been incorporated in aerodynamic theory since first studied. Initial research termed the point in a flow regime where separation begins as the burble point. Researchers then studied the interference burble, which is the flow separation caused by joining of aircraft surfaces. With expanded capabilities for aircraft study and performance, the compressibility burble was the term used for the separation region behind a supersonic compression-shock. The term burble has been applied to geometries designed to disturb flow as well as noise attributed to vortex wake interactions. Most recently, burble has been used to describe turbulent flow wake behind an aircraft carrier.

The history of the term burble is the story of an interim word for a specific term. Published words show trends away from the use of the term burble, shifting to more specific terms. The semantics of the term burble show it has been dropped due to lack of specificity. The influence of the term burble on aerodynamic theory is rooted in the unknown. The history of burble is encouraging to contemporary researchers who study the yet-unexplained aspects of aerodynamics and flight mechanics.

Historical reviews such as the present paper provide a succinct summary and definition of an unfamiliar word for the reader. While some unfamiliar words can be understood from context, others require extensive research to define. Indeed, the authors learned of the term burble from the review of aerodynamic theory edited by Durand [47]. A review such as the present paper would have been invaluable to understand the context and rich historical usage of the term burble. The history of the word burble can guide future students of aerodynamics in understanding how flow separation has been studied in various flow regimes. This history also gives hope to the researchers who try to pave new roads.

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