Enhanced definition and required examples of common datum imposed by ISO standard

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Abstract. According to the ISO Geometrical Product Specifications (GPS), the establishment and definition of common datum for geometrical components are not fully defined. There are two main limitations of this standard. Firstly: the explications of ISO examples of common datums are not matched with their corresponding definitions, and secondly: a full definition of common datum is missing. This paper suggests a new approach for an enhanced definition and concrete examples of common datum and proposes a holistic methodology for establishment of common datum for each geometrical component. This research is based on the analysis of physical behaviour of geometrical components, orientation constraints and invariance classes of datums. This approach fills the definition gaps of common datum based on ISO GPS, thereby eliminating those deficits. As a result, an improved methodology for a fully functional defined definition of common datum was formulated.

1. Introduction
ISO 5459:2013 [1] is the international Geometrical Product Specifications (GPS) [2] standard for definition and establishment of common datum of geometrical components in design and manufacturing. In ISO 5459:2013 the examples are not matched with the corresponding definitions of common datums. Moreover, there are only two kinds of examples for common datum establishments with the same invariance class of geometrical components: one is with only parallel planes and another is with only parallel axes. It causes an incomplete definition of common datum establishment for geometrical components containing nonparallel planes and axes. This paper forces on the development of an unambiguous definition and an improved holistic methodology for function-oriented establishment of common datum for every geometrical component. This research is based on the analysis of physical behaviour of geometrical components, orientation constraints and invariance classes of datums.

The previous works [3-12] concentrated more on the mathematical filtration process and practical application of single datums and datum systems, rather than the development of explicit and complete definition of common datum and function-oriented common datum establishment process.

This paper proposes an enhanced definition and required examples of common datum and gives a new holistic approach for the establishment process of common datum. This paper is constructed as follows: section 2 describes the state of the art including basic theory and terminologies of common
datum for geometrical parts from the current ISO standards and examples from ISO with their corresponding deficits. A new enhanced definition with corresponding examples and an improved holistic methodology are given in section 3. The conclusion and outlook is written in section 4.

2. State of the art and deficits

2.1. Terminology
In order to understand the research and purpose of this paper, the following important terminologies are explicated with the definitions and the illustrations:

- **Situation feature**: point, straight line, plane or helix from which the location and orientation of features, or both, can be defined [1].
- **Datum feature**: real integral feature used for establishing a datum [1].
- **Datum feature indicator**: single features to be used for establishing datum features shall be indicated [1]. The symbol is shown in Figure 1.

![Figure 1](image.png)

**Figure 1.** Datum feature indicator: a) box linked to a filled, b) open datum triangle by a leader line [1].

- **Datum**: is a theoretically exact reference; It is defined by a plane, a straight line or a point, or a combination thereof [1].
- **Common datum**: datum established from two or more datum features considered simultaneously. To define a common datum, it is necessary to consider the collection surface created by the considered datum features [1].
- **Collection surface**: two or more surfaces considered simultaneously as a single surface. When two intersecting planes are considered simultaneously as a single surface, that surface is a collection surface [1].
- **Invariance class**: group of ideal features for which the nominal surface is invariant for the same degree of freedom. The number of invariance degrees is equal to the number of unconstrained degrees of freedom for a given geometrical feature [1]. All geometrical component has 6 degree of freedom (DOF) which contains 3 translations in X, Y and Z direction and 3 rotations around each axis [13-15]. For example: the invariance class of a sphere is spherical. Its datum is the middle point and constrains 3 translations; the invariance class of a plane is planar. Its datum is a plane and constrains 1 translation and 2 rotations; the invariance class of a cylinder is cylindrical. Its datum is the straight line (axis) and constrains 2 translations and 2 rotations [1].

2.2. Examples from ISO: definitions and establishments of common datums

2.2.1. **Example 1: common datum with two parallel planes.**
Figure 2 illustrates the establishing process of common datum by two parallel planes imposed by ISO example. Single parallel datum plane A and B are in part a) and their common datum plane A-B is the middle plane of A and B which shows in c).

![Figure 2](image.png)

**Figure 2.** a) two parallel datum planes A and B, b) key 1: datum features, key 2: associated features [16]: theoretical exact single datum planes A and B, c) key 3: common datum- situation feature of the collection surface is the middle plane A-B [1].
2.2.2. Example II: common datum with two parallel axes.
Figure 3 illustrates another example from ISO for establishment of common datum from two parallel datum axes. The single datums of two cylinders are axes A and B. Based on the ISO explanation of this example, their common datum A-B is a plane and a straight line (see Figure 3 c). The plane contains two axes and the straight line is the median straight line of these two axes [1].

![Figure 3](image)

Figure 3. ISO example of common datum with two parallel axes. a) two parallel datum axes A and B, b) key 1: single datum axes A and B, key 2: associated features: theoretical exact cylinders, c) key 3: common datum-situation feature of the collection surface: a plane and a straight line [1].

2.3. Deficits of ISO examples
Based on the ISO definitions of common datum and collection surface in section 2.1 and the explanations of ISO examples in section 2.2, there are two main deficits to be recognised.

Deficit 1: according to the definition of common datum, two datum features in Example II should be considered simultaneously and under the collection (bisection) process. Thereby the common datum should be the median straight line of both datum axes from these two datum features. This is contradictory to the ISO explanation in Figure 3c) which is a plane and a line. Moreover, the ISO definition defines the necessity of consideration of collection surface during common datum establishment. Example II defines the collection surface of these two datum axes which is a plane and a straight line. It is also a contradiction to the original definition of collection surface which is only a surface without straight line.

Deficit 1: The explanation of Example II does not fit the ISO definition of common datum and collection surface. Straight line and plane are not collection surface and the median straight line is not the common datum A-B.

Another deficit is, there are only parallel datum features with the same invariance class (planes and axes) that are taken into account in the ISO examples. A datum is defined by a plane, a straight line and a point. A systematic methodology for definitions and establishment of common datums with concrete examples for the non-parallel datum features including all the situation features of datum are missing.

Deficit 2: The definitions and examples of establishments of common datums imposed by ISO are not complete. A holistic methodology of common datum establishment of planes, straight lines and points is missing.

3. New approach
This section proposes a new approach by analysis of physical behaviour of geometrical components, orientation constraints / DOF between datums and invariance class of datum features. The following section 3.1 enhances the definitions of terminologies of common datum and collection surface. Section 3.2 gives a holistic methodology to improve the completeness of establishment of common datum by using concrete examples. Section 3.2 subclassifies the holistic methodology into three catalogues
based on the situation features of datum which are a plane, a straight line (in this paper, it is an axis of a cylinder) and a point (in this paper, it is a middle point of a sphere).

3.1. Expansion of definition of common datum
In order to eliminate the Deficit 1 where the definitions of common datum and collection surface do not match the explanations of ISO examples, a function-oriented and enhanced definitions thereof should be added. The function of a common datum of a geometrical component should constrain the same DOF which are constrained through the single datums. The invariance class of a common datum can be the same invariance class of each single datums, but it is not a must (another invariance class is permitted). Important is that the invariance class of a common datum constrain the same DOF which the single datums constrain. It is not necessary to consider the collection surface of the single datums, because not all the common datum of geometrical component is a surface. The thought model of a collection surface can be only applied by the establishment of a common datum by a geometrical component with two parallel single datum planes. Based on the above reasons, the following definition of a common datum is enhanced:

Improvement 1: Enhancement of definition of common datum.
   Common datum: To define a common datum, it is not always necessary to consider the collection surface created by considered datum features. The result of a common datum should not constantly created through the simple collection process of each single datum features. The established common datum should constrain the same degree of freedom as the single datum features collaborative constrain.

3.2. Holistic methodology of definition of common datum by planes, straight lines and points
This paper proposes a completeness of definition of common datum with the geometrical components which are frequently applied in practice. Based on the definition of ISO, datum is distinguished by a plane, a straight line and a point. In practice, datum straight line is mostly considered as an axis of a cylinder and datum point is considered as a middle point of a sphere. Therefore, subsections 3.2.1-3.2.3 give three corresponding holistic methodologies of definitions and examples of common datums separately by planes, axes and middle points. Nevertheless, the corresponding examples do not have just parallel datum features in one geometrical component.

3.2.1. A holistic methodology of definitions and examples for “plane-plane” common datum.
For a geometrical component with two planes as datum features, there are three situations of relative orientation of datum feature planes: parallel, perpendicular and with a defined angle. Figure 4 illustrates the holistic methodology of definitions and examples of the “plane-plane” common datum in each cases. When two datum feature planes are parallel, their common datum plane A-B is the bisector plane of A and B which is defined by ISO. Based on ISO, the notation of A-B and B-A have the identical meaning. When these two planes are perpendicular, the common datum A-B is the combination of datum plane A and a straight line in A. This straight line is the intersection line of plane A and plane B. In this case, A-B has a different meaning to B-A. This methodology defines, when A is notated in the first place of A-B, then A is the datum plane in the common datum. If B-A is written, then B is defined as the datum plane in the common datum. These both single datum planes A and B constrain totally 5 DOF and the new functionally established common datum A-B constrains 5 DOF as well. If the establishment of common datum based on the original definition of ISO in section 2.1, the common datum A-B should be the bisector plane of A and B which is a 45° inclined plane. This is false because the constrained DOF of a plane is only three. Analog to the perpendicular case, the third case with a defined angle have the same common datum A-B as in the second case. The common datum A-B is a combination of datum plane A (because A is notated in the first place of A-B) and the intersection line of plane A and B. In this case, the common datum A-B and B-A have different meaning in analogy to case II.
3.2.2. A holistic methodology of definitions and examples for “axis-axis” common datum. 
Figure 5 illustrates the holistic methodology of establishment of “axis-axis” common datum by geometrical components with three cases of relative orientation of two single datum axes A and B. Case I is a part with two parallel axes A and B, the common datum A-B is a combination of a plane which contains both axes and a straight line. The straight line is a virtual middle line of both axes. The notations of A-B and B-A have the identical meaning, because of the parallelism of A and B. This is defined by ISO. Case II shows a part with two perpendicular cylinders with two datum axes A and B. They constrain all the DOF of this part where the part is now fixed in space. The common datum A-B is a combination of a plane, a straight line and a point which block all the DOF of this part. The plane contains axes A and B, the straight line is the axis A and the point is the intersection point of axes A and B. In this case, the methodology defines that the definition of A-B is different with B-A, because of the non-parallelism of axes A and B. When the common datum is notated as B-A, so the straight line in the common datum is the axis B instead of axis A. Analog to case II, case III with two cylinders by a defined angle has also the same common datum A-B with a combination of a plane, a straight line (axis A) and a point. The establishing process of the plane, straight line and point is the same as in case II. The meaning of common datum A-B and B-A is also different in analogy with case II.

3.2.3. A holistic methodology of definition and example for “point-point” common datum.
The example and definition of establishment of common datum by a geometrical component with spheres is completely missing in the current ISO. Figure 6 gives a definition and example of common datum by two spherical datum features A and B. Mathematically there is no parallelism and perpendicularity between two points. Therefore, theoretically the description of relation between two points in space is named: relative orientation. Figure 6 shows a component with two single datum middle points A and B, their common datum A-B is a combination of a straight line (which is the
connection of middle points A and B) and the virtual middle point (centring point) of A and B. The common datum A-B allows this part only one DOF which is the rotation around the straight line. This is the same as when the single datum points A and B have collaborative constrain. The meaning of common datum A-B and B-A is the same in this case, because of the relative orientation statues which include the interpretation of parallelism.

![Diagram of point-point common datum](image)

**Figure 6.** Holistic methodology of “point-point” common datum A-B by geometrical component with two spherical datum features A and B. The common datum is a combination of a straight line and a point.

Section 3.2 describes a function-oriented, clarified and fully defined holistic methodology, in which the geometrical components with two relative oriented planes, straight lines and points are explicated with corresponding practical examples. The definition of common datum notation A-B and B-A are also given in this section. This section eliminates the Deficit 2.

| Improvement 2: Complement of definition of common datum. A holistic methodology of definitions and examples of common datum is developed. |

4. Conclusion and outlook

This paper presented a novel approach for the enhanced definition and required examples of common datum imposed by ISO. A holistic methodology of establishment of common datum by geometrical components with different oriented planes, straight lines and points were developed with concrete examples. This new approach eliminated the deficits and limitations imposed by ISO standard. Moreover, a new thought model of establishment of common datum by considering the DOF rather than collection surface was formulated as well. Future work involves defining the definition of common datum by mixed combination of planes, straight lines (not only axes) and points (not only middle points). Nevertheless, further work will also contain a study on more than 2 single datums by establishing a common datum. A hypothesis to a complex common datum like A-B-C with different invariance classes as datum features in one geometrical component is: the common datum should constrain the same DOF as the single datums collaborative constrain.

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